



Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats

MIT Lincoln Laboratory (lead organization)

William J. Blackwell, Principal Investigator. Scott Braun (NASA GSFC), Project Scientist



2017 PMM Meeting

R. Atlas
R. Bennartz
M. DeMaria
J. Dunion
F. Marks
R. Rogers
C. Velden
D. Herndon
K. Clark
S. Michael
L. Fuhrman
V. Leslie
J. Eshbaugh

TROPICS will provide
better than 60-minute
refresh over entire
tropical cyclone belt

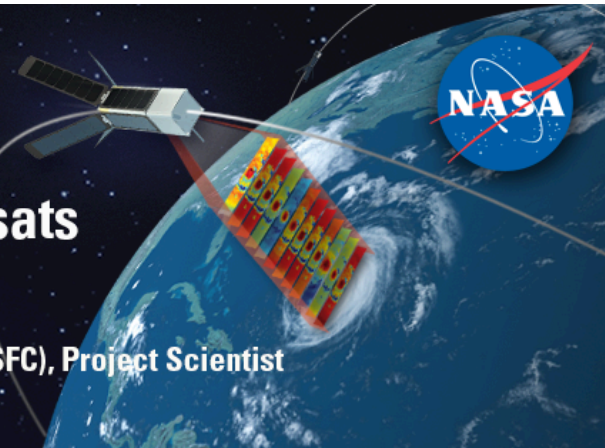
<https://tropics.ll.mit.edu>



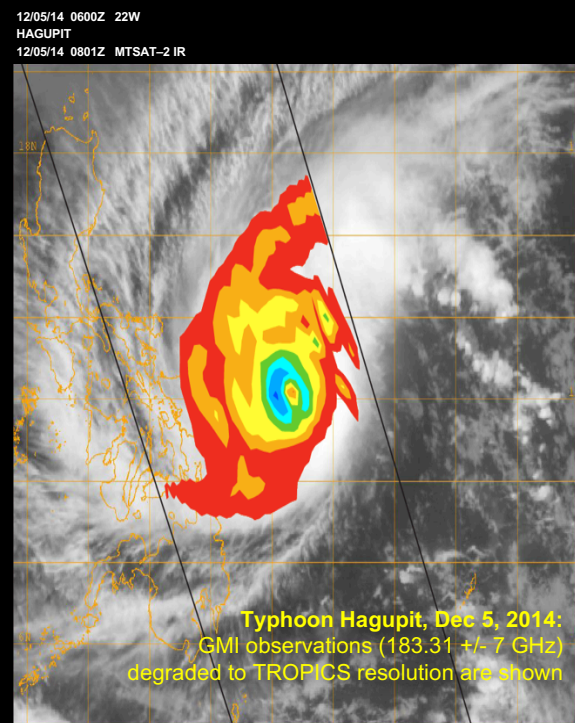
Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats

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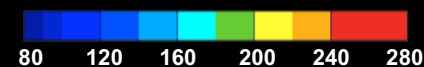
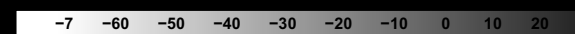
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- TROPICS will be the first demonstration that science payloads on low-cost CubeSats can push the frontiers of spaceborne monitoring of the Earth to enable system science.
- TROPICS will fill gaps in our knowledge of the short time scale—hourly and less—evolution of tropical cyclones. Our current capabilities are almost an order of magnitude slower.
- TROPICS will complement CYGNSS by making direct measurements of temperature, humidity and precipitation, in rapidly developing tropical cyclones.
- TROPICS has the potential to make frequent precipitation measurements, expanding on the coverage of the GPM mission.



Naval Research Lab http://www.nrlmry.navy.mil/sat_products.html
<--- IR Temperature (Celsius) --->

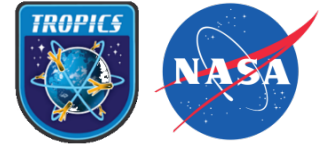


TB (K)

<https://tropics.ll.mit.edu>



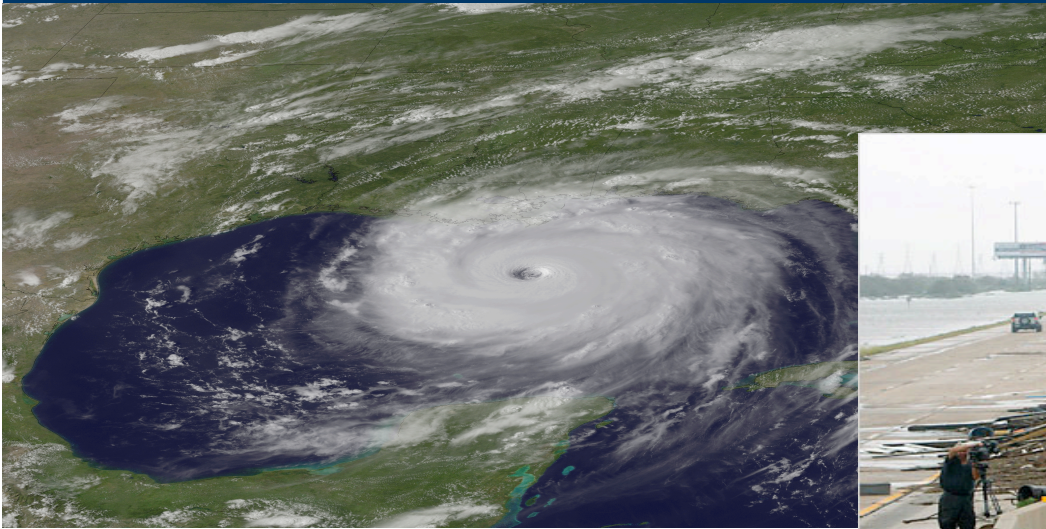
Outline



- **Introduction and motivation**
- **Passive microwave sounding CubeSats**
- **TROPICS overview and status**
 - **Science objectives**
 - **CubeSat constellation observatory**
 - **Mission implementation**
- **Summary and path forward**



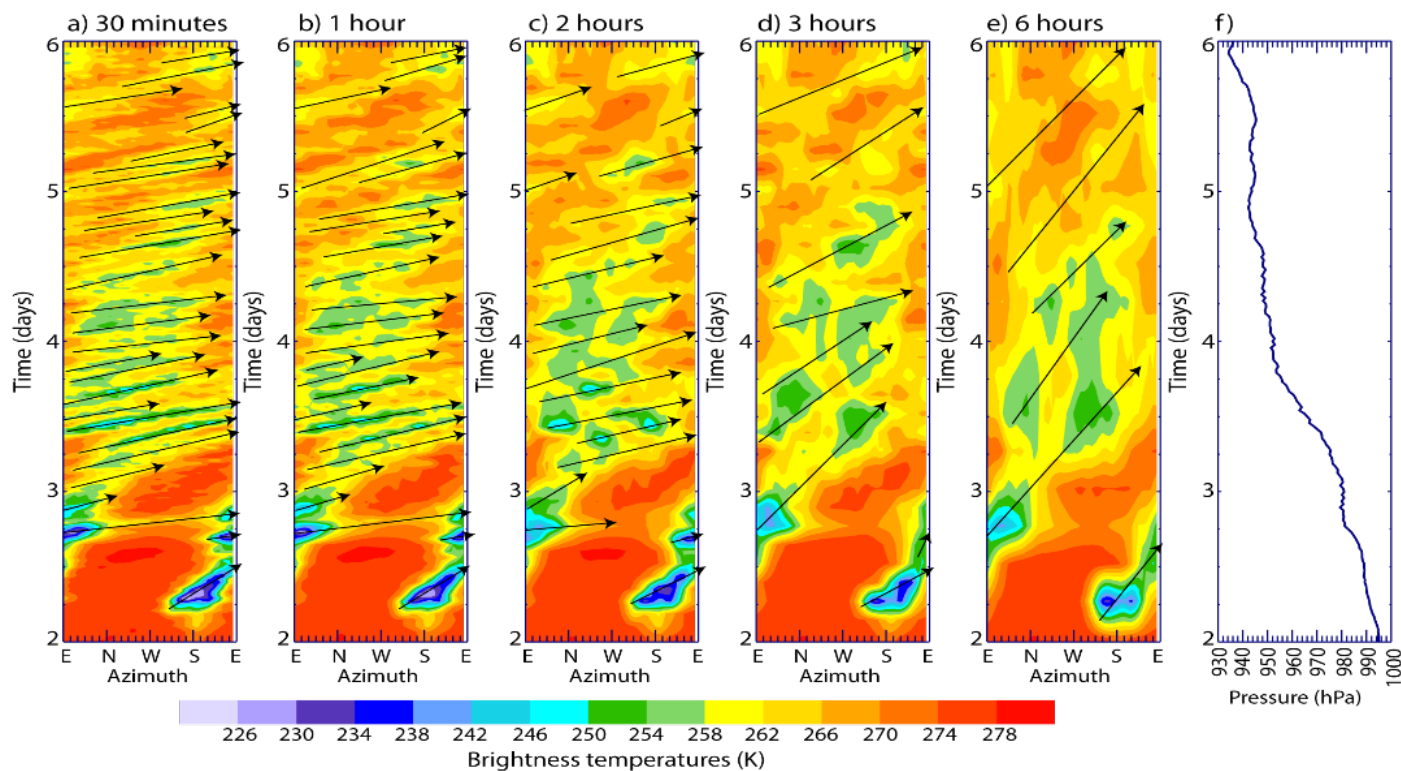
Weather Prediction has Profound Societal and Economic Implications



- The US derives \$32 B of value from weather forecasts annually¹
- Earth observing satellites drive the forecasts
- Eternal quest for resolution: Spatial (vertical and horizontal), temporal, and radiometric



Revisit Rate Requirements

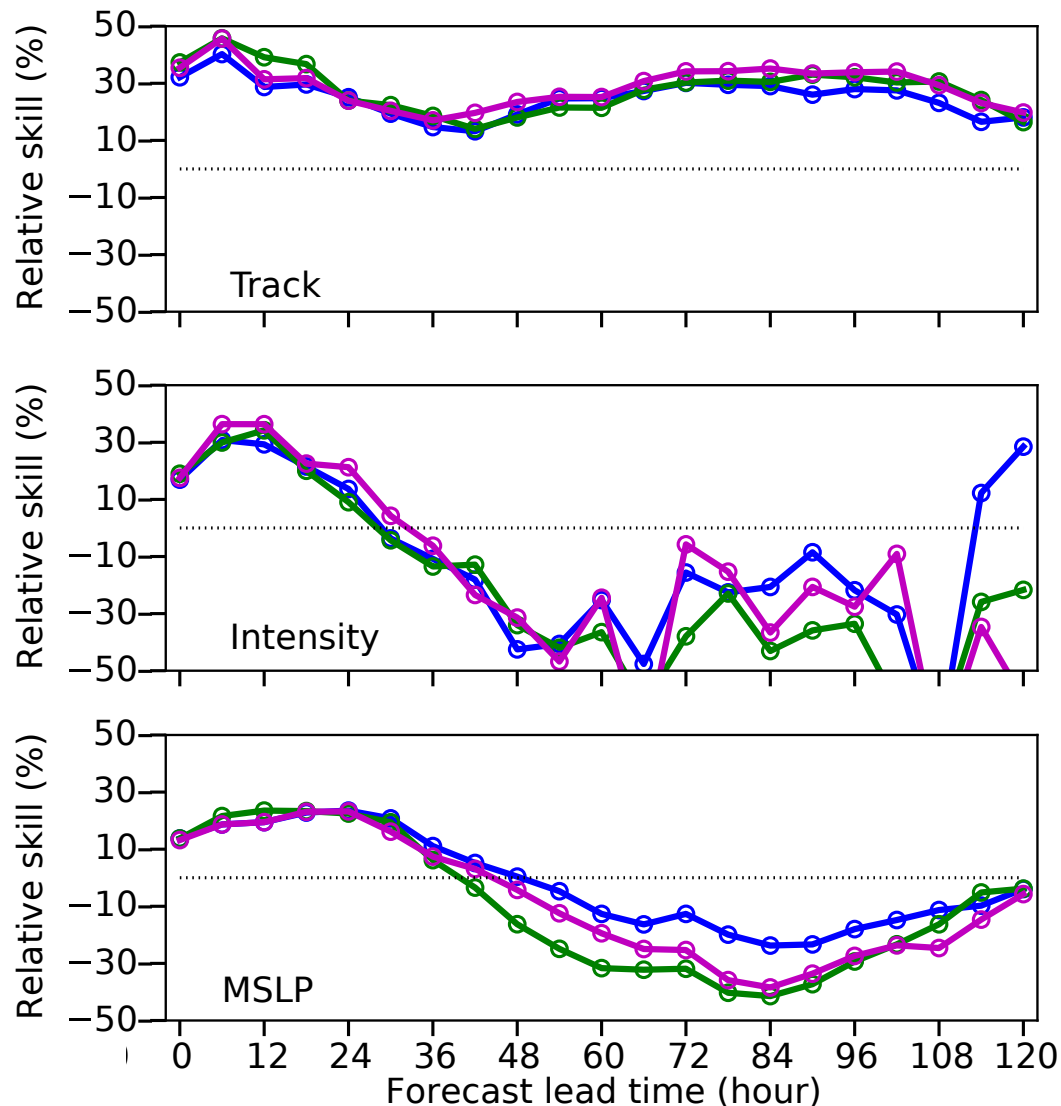


Baseline:
60-min Median

Threshold:
120-min Median



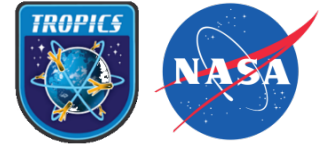
NOAA AOML OSSE for Baseline TROPICS Configuration (Green)



- Nolan (2013) Hurricane Nature Run used to simulate TROPICS measurements at appropriate geometry and temporal revisit
- 2014 HWRF was used (3D-var assimilation)
- Native resolution (~20/40 km) was thinned to 50 km



Outline



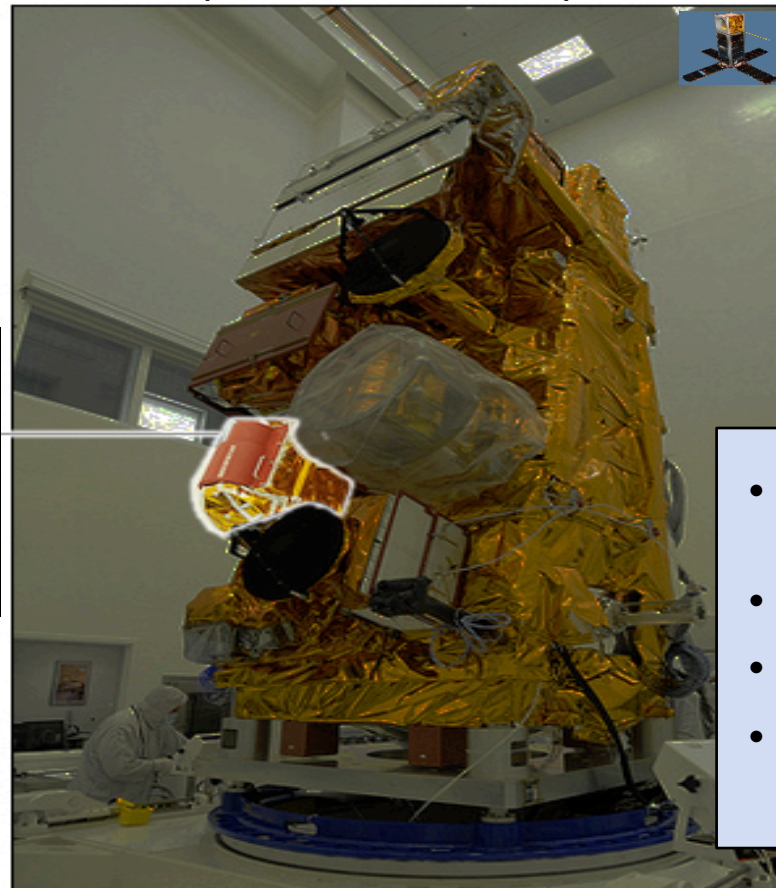
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New Approach for Microwave Sounding



**Suomi NPP Satellite
(Launched Oct. 2011)**

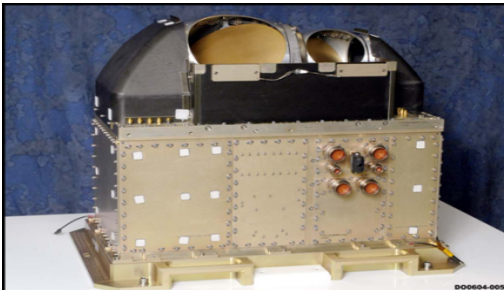


2100 kg

NASA/GSFC

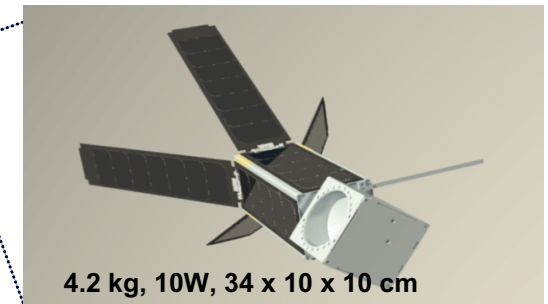
NPP: National Polar-orbiting Partnership

**Advanced Technology
Microwave Sounder
(ATMS)**



100 kg, 100 W

MicroMAS Satellite



4.2 kg, 10W, 34 x 10 x 10 cm

- Microwave sensor amenable to miniaturization (10 cm aperture)
- Broad footprints (~50 km)
- Modest pointing requirements
- Relatively low data rate



TROPICS Pathfinders: MicroMAS-1, MicroMAS-2, and MiRaTA



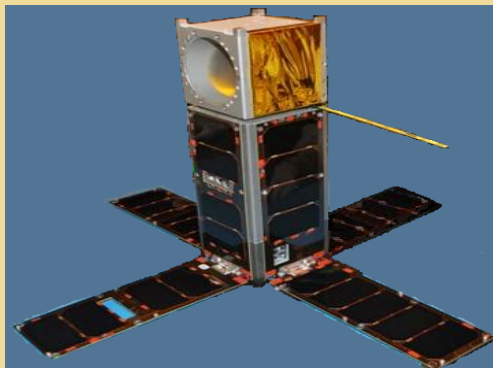
MicroMAS = Microsized Microwave Atmospheric Satellite
MiRaTA = Microwave Radiometer Technology Acceleration

MicroMAS-1

3U cubesat with 118-GHz radiometer

8 channels for temperature measurements

July 2014 launch, March 2015 release; validation of spacecraft systems; eventual transmitter failure



MicroMAS-2

3U cubesat scanning radiometer with channels near 90, 118, 183, and 206 GHz

Channels for moisture and temperature profiling and precipitation imaging

Launch in 2017 in 2018

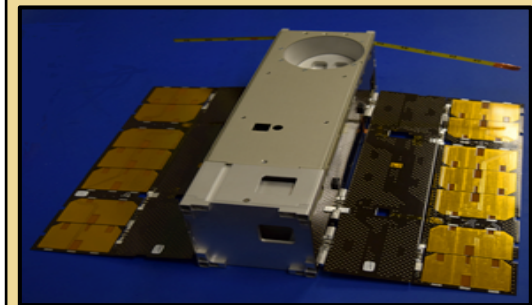


MiRaTA

3U cubesat with 60, 183, and 206 GHz radiometers and GPS radio occultation

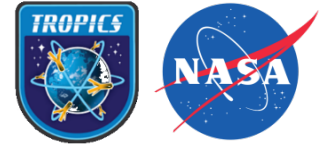
10 channels for temperature, moisture, and cloud ice measurements

2017 launch on JPSS-1





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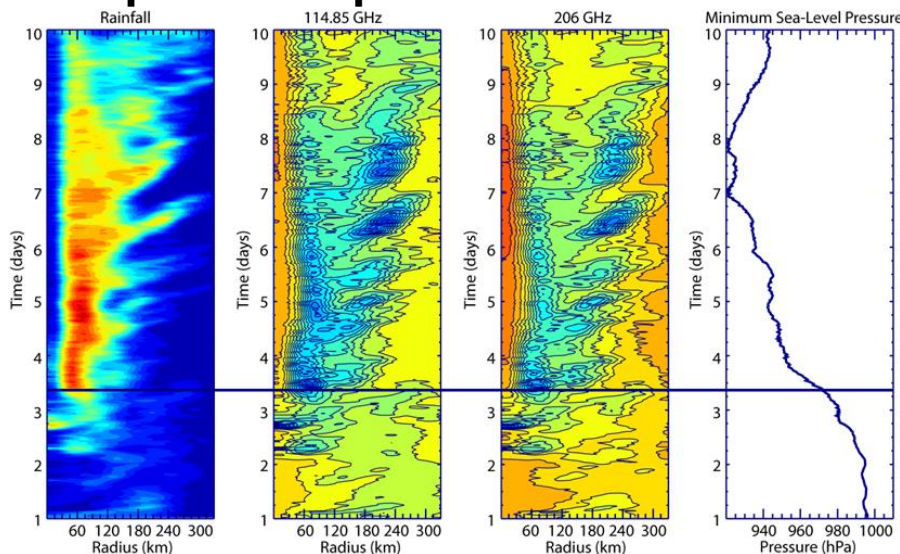


TROPICS Science Objectives

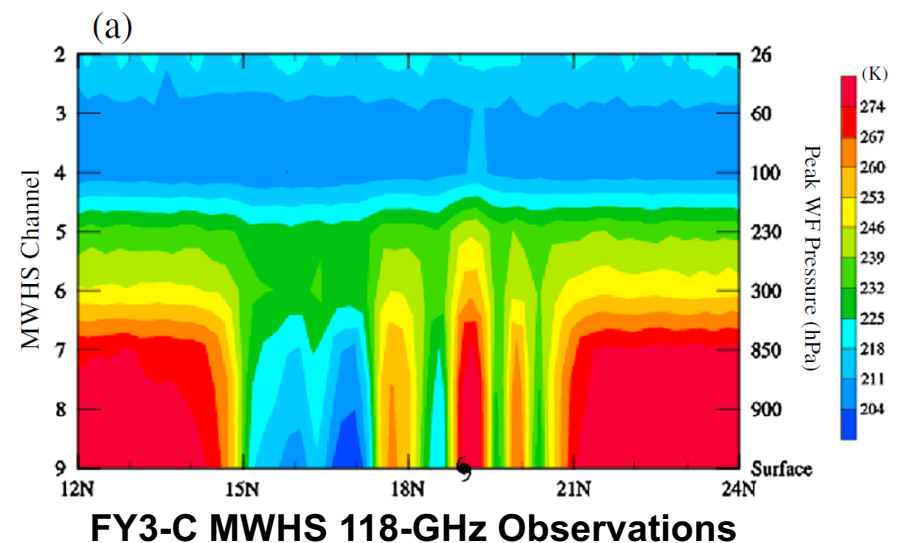


- Relate precipitation structure evolution, including diurnal cycle, to the evolution of the upper-level warm core and associated intensity changes
- Relate the occurrence of intense precipitation cores (convective bursts) to storm intensity evolution
- Relate retrieved environmental moisture measurements to coincident measures of storm structure (including size) and intensity
- Assimilate microwave observations in mesoscale and global numerical weather prediction models to assess impacts on storm track and intensity

Spatio-Temporal Characteristics



Spectral Characteristics

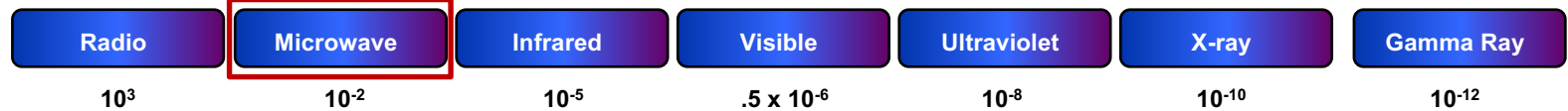




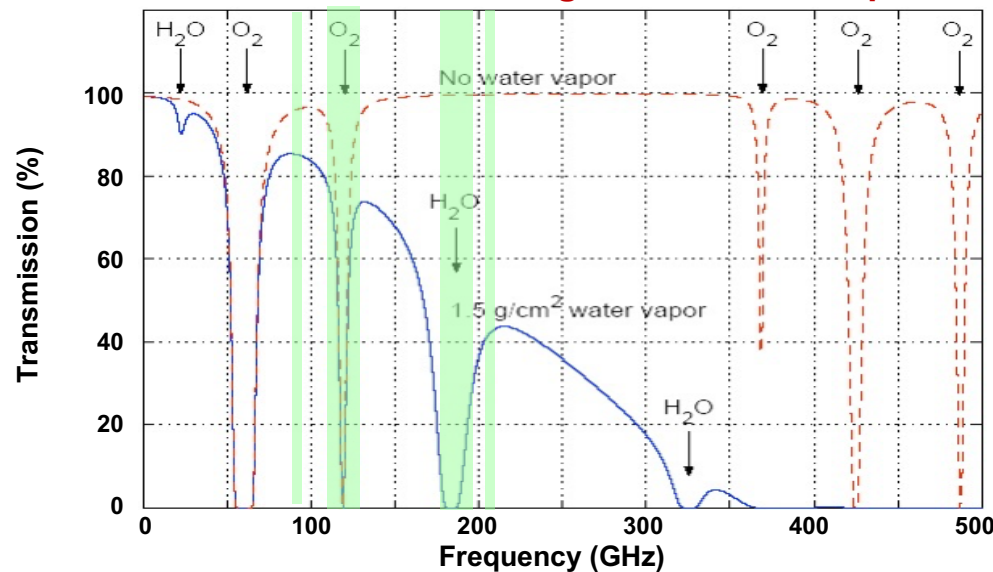
Microwave Atmospheric Sensing



Wavelength
(meters)



Cloud Penetration; Highest Forecast Impact



The frequency dependence of atmospheric absorption allows different altitudes to be sensed by spacing channels along absorption lines

Sampling in multiple carefully chosen channels will allow development of AVTP, AVMP, ISRR, MSWS and MSLP



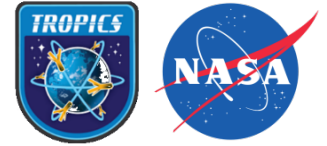
TROPICS Products and Expected Performance



Product	Threshold Requirement (Uncertainty)	Baseline Requirement (Uncertainty)	Expected Performance (Uncertainty)
Temperature Profile	2.5 K	2.0 K	1.6 K
Moisture Profile	35 %	25 %	16 %
Rain Rate	50 %	25 %	25 %
Min Sea-Level Pres.	12 hPa	10 hPa	8 hPa
Max Sustained Wind	8 m/sec	6 m/sec	5.5 m/sec



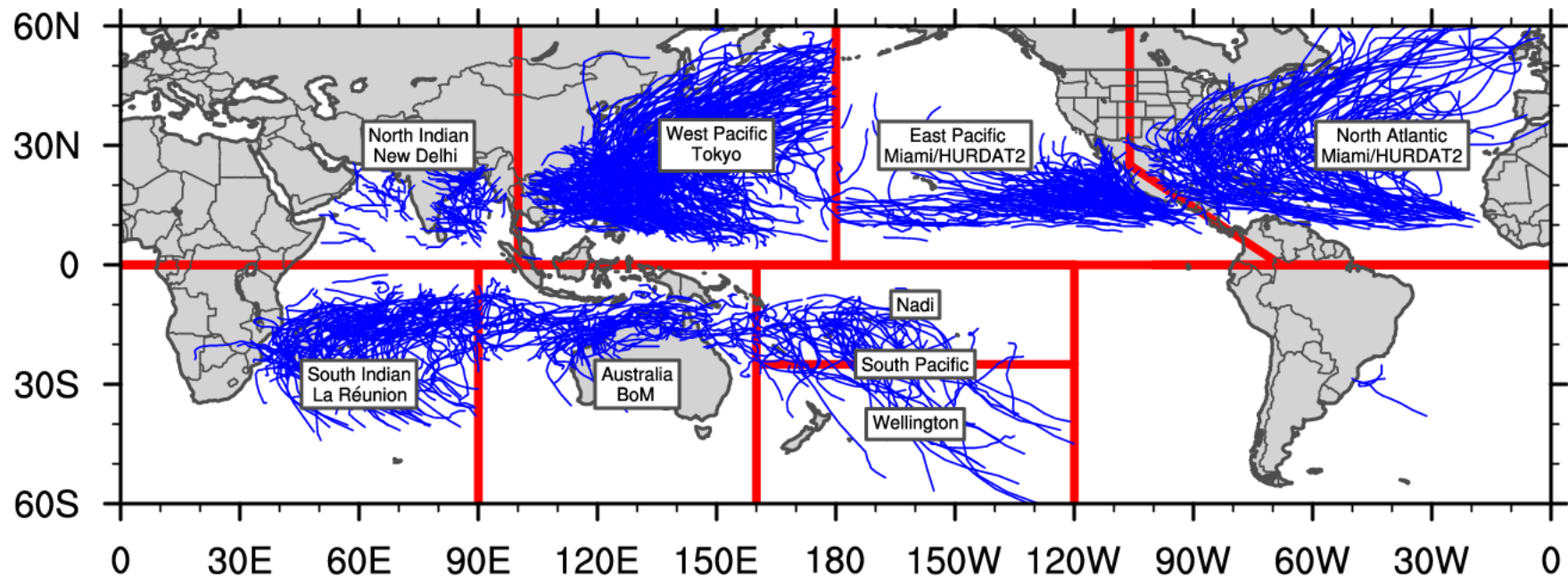
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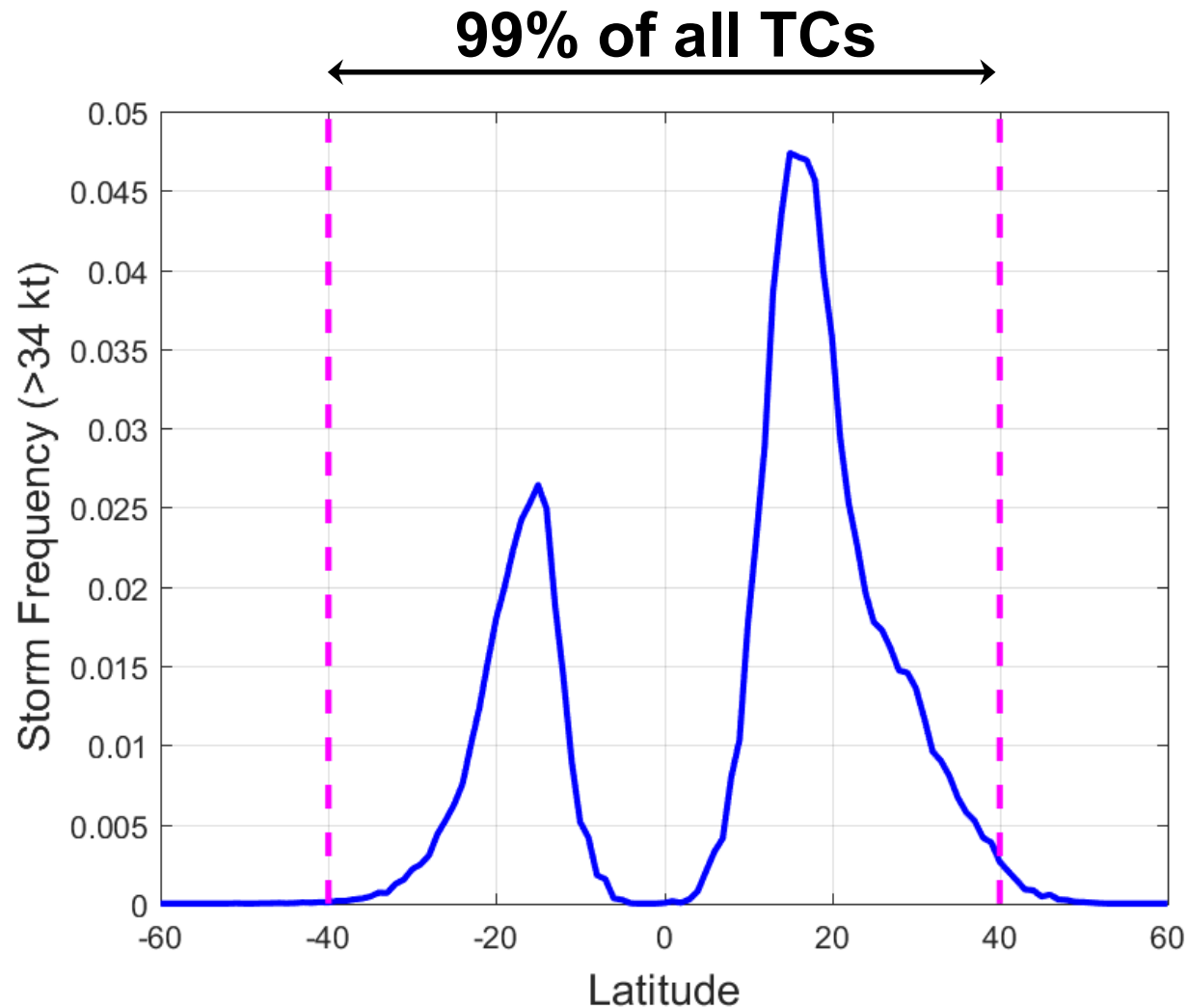


Historical Tropical Cyclone Tracks (1985-2014)





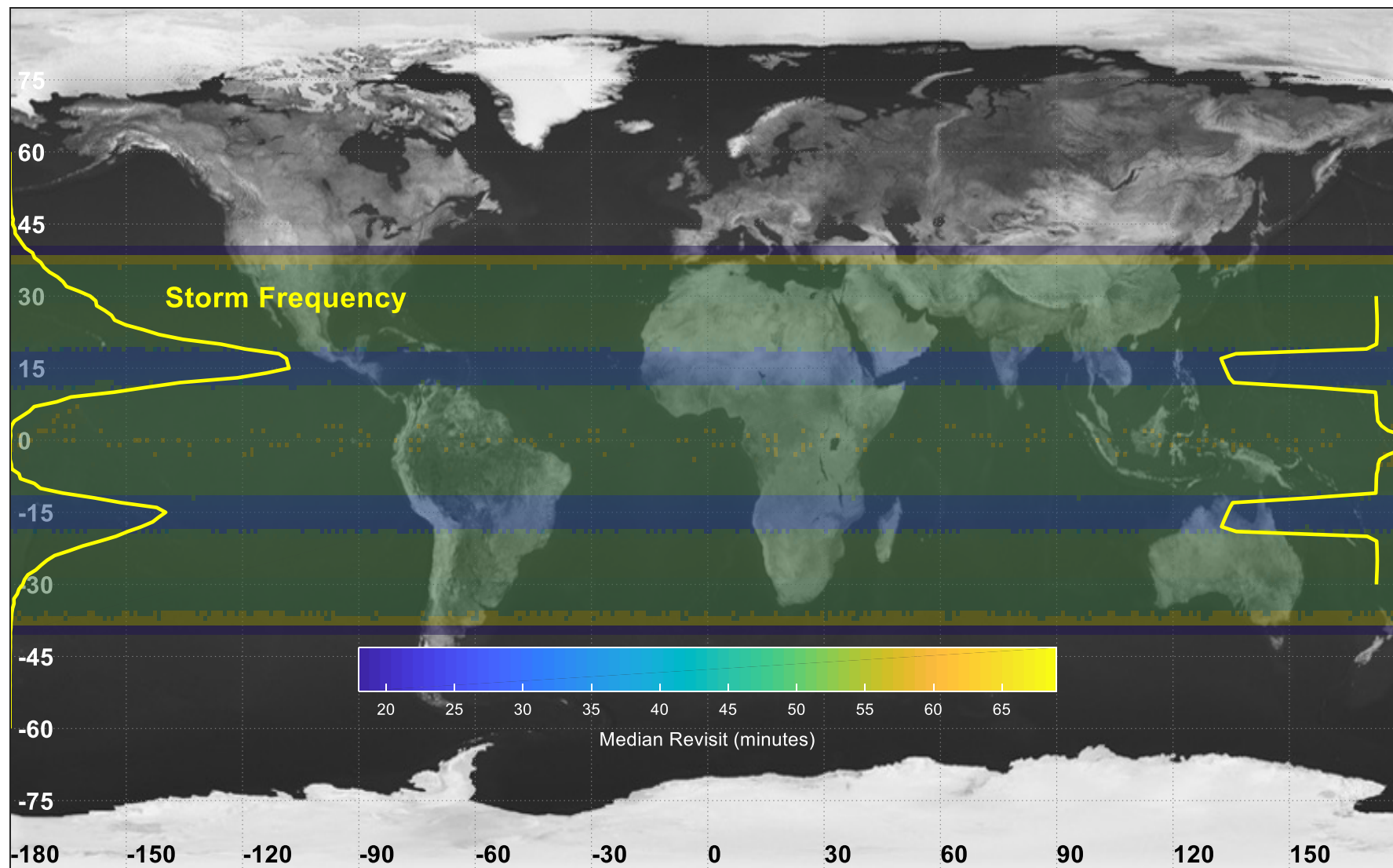
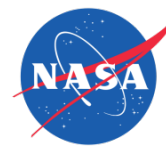
Historical TC Frequency vs Latitude





TROPICS Revisit

(6 sats, 3 planes, 30° inc., 550 km alt.)





TROPICS Channel Set

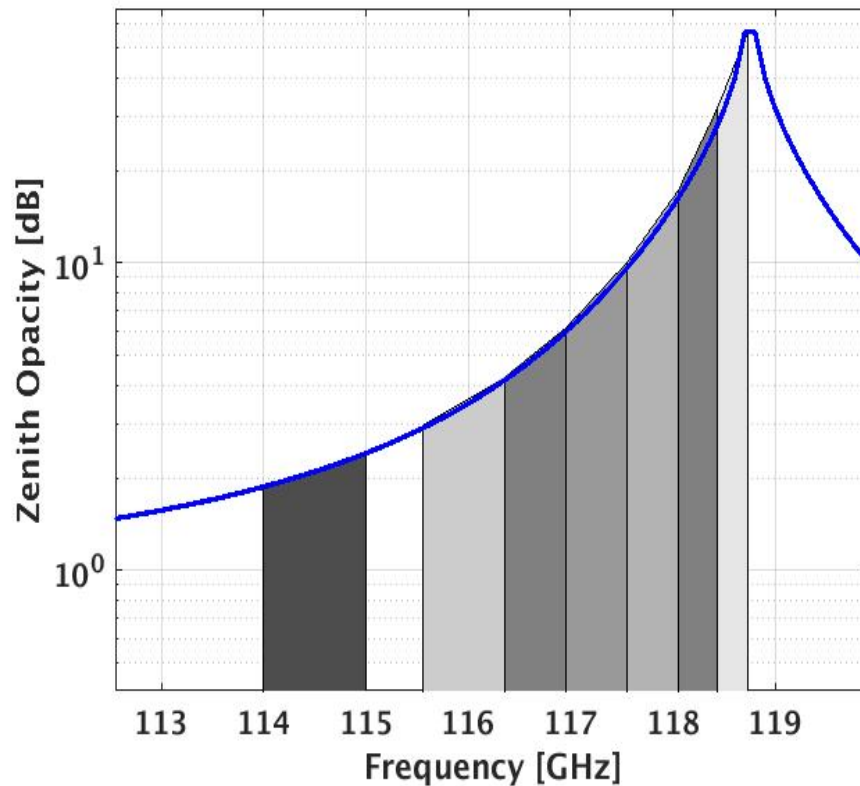


TROPICS Chan.	Center Freq. (GHz)	Bandwidth (GHz)	RF Span (GHz)	Beamwidth (degrees) Down/Cross	Nadir Footprint Geometric Mean (km)*	Expected NEdT (K)
1	91.656 \pm 1.4	1.000	89.756-90.756, 92.556-93.556	3.0/3.17	29.6	0.95
2	114.50	1.000	114.00-115.00	2.4/2.62	24.1	0.55
3	115.95	0.800	115.55-116.35	2.4/2.62	24.1	0.60
4	116.65	0.600	116.35-116.95	2.4/2.62	24.1	0.70
5	117.25	0.600	116.95-117.55	2.4/2.62	24.1	0.70
6	117.80	0.500	117.55-118.05	2.4/2.62	24.1	0.75
7	118.24	0.380	118.05-118.43	2.4/2.62	24.1	0.85
8	118.58	0.300	118.43-118.73	2.4/2.62	24.1	1.00
9	184.41	2.000	183.41-185.41	1.5/1.87	16.9	0.60
10	186.51	2.000	185.51-187.51	1.5/1.87	16.9	0.60
11	190.31	2.000	189.31-191.31	1.5/1.87	16.9	0.60
12	204.8	2.000	203.8-205.8	1.35/1.76	15.2	0.60

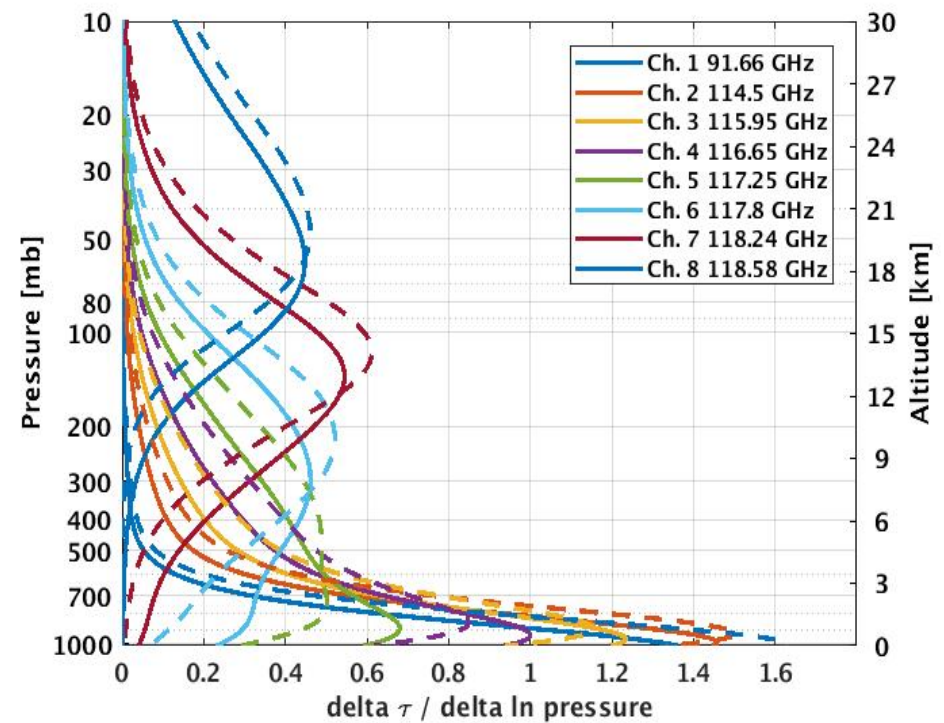
* 550 km altitude



F-band Temperature Weighting Functions



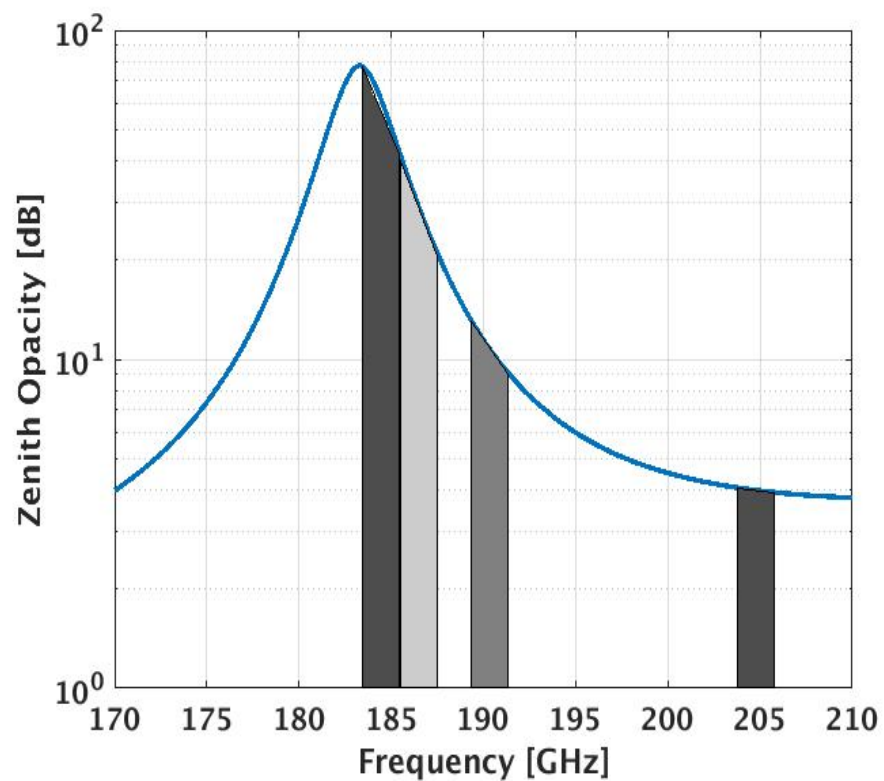
TROPICS



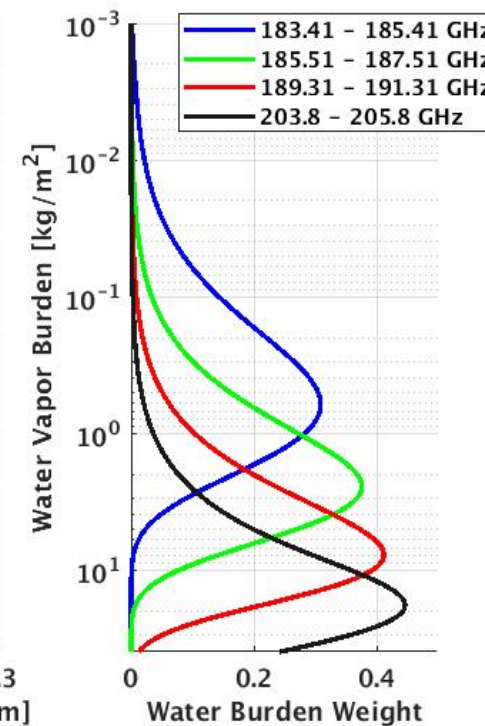
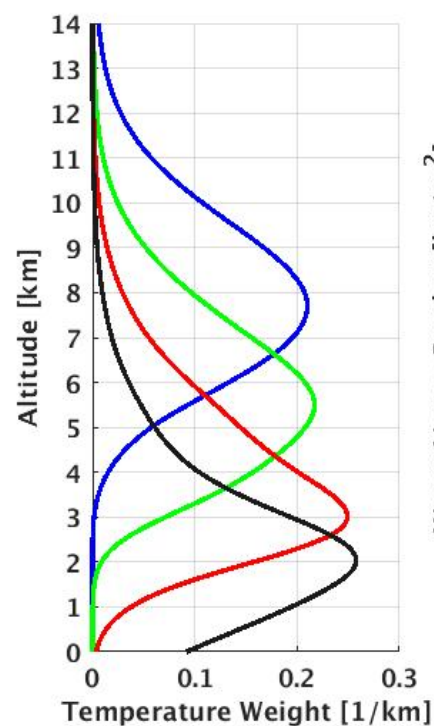
Solid are nadir and dashed are 50°
US 1976 Tropical Standard Atmosphere



G-band Weighting Functions



TROPICS



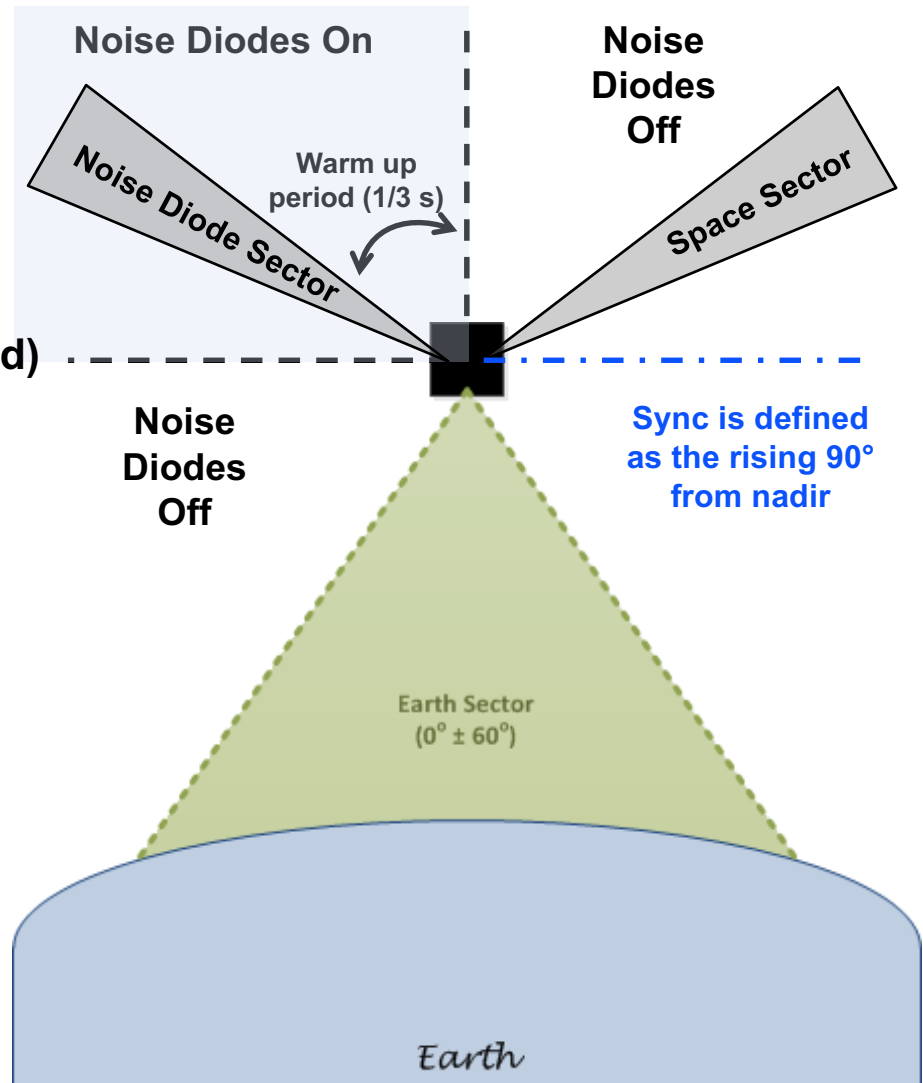
Nadir angle
US 1976 Tropical Standard Atmosphere



Scan Profile for TROPICS



- Rotation rate is 30 RPM (2 sec. period)
- 81 Earth Sector samples per scan
- 10 samples each in Space & ND Sectors
- Integration time: 8.333 msec (1/120 second)
- Spatial Information (at 550 km):
 - Beamwidth (FWHM):
 - W-band 3.0° DT (3.2° CT)
 - F-band 2.4° DT (2.62° CT)
 - G-band 1.5° DT (1.87° CT)
 - Sample spacing: 1.5°
 - Swath: ~2000 km
 - Nadir footprint diameter
 - W-band: 26-km DT, ~28-km CT
 - F-band : 22-km DT, ~24-km CT
 - G-band : 13.1-km DT, ~17.1-km CT





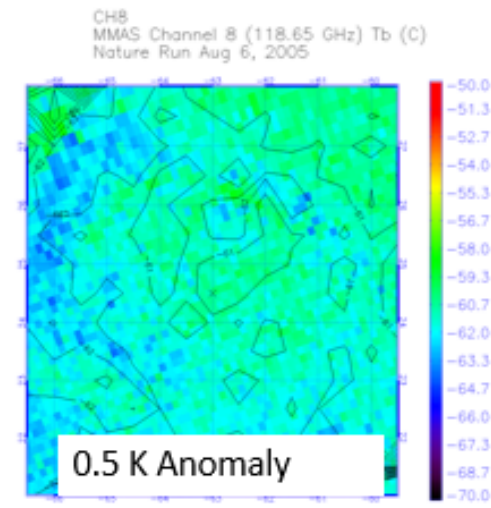
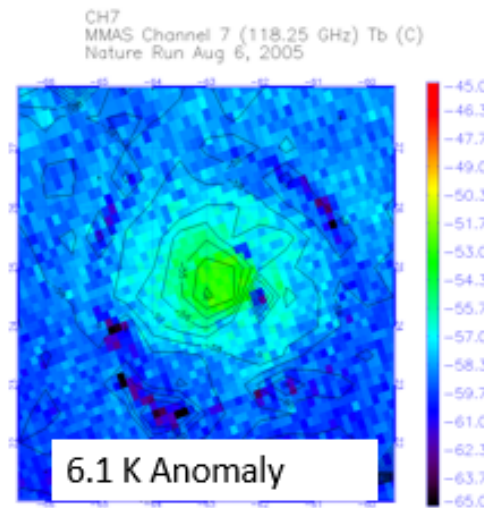
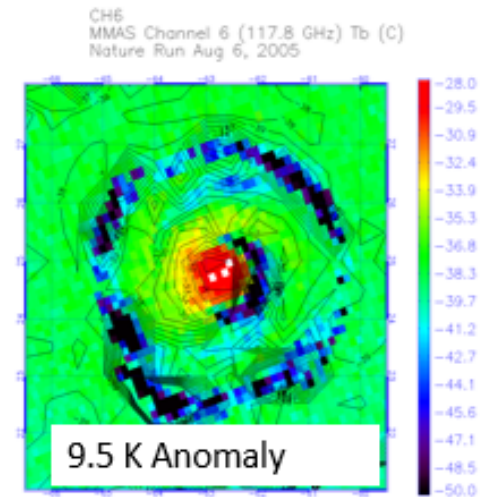
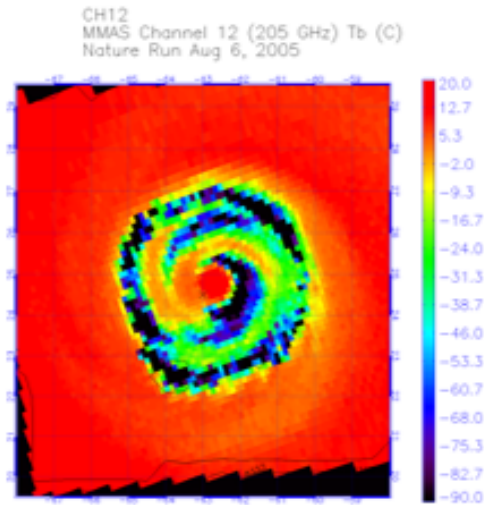
Simulated Warm Core Anomalies Strong Storm: 110 kn



**MMAS2 Nature Run
Test 2 with a stronger
Tropical Cyclone**

**TC exhibits secondary
eyewall in CH 12**

**Large eye allows sensor
to resolve warm anomaly**



Max Tb (C): -52.5 Contour Interval = 1C
University of Wisconsin - CMSS

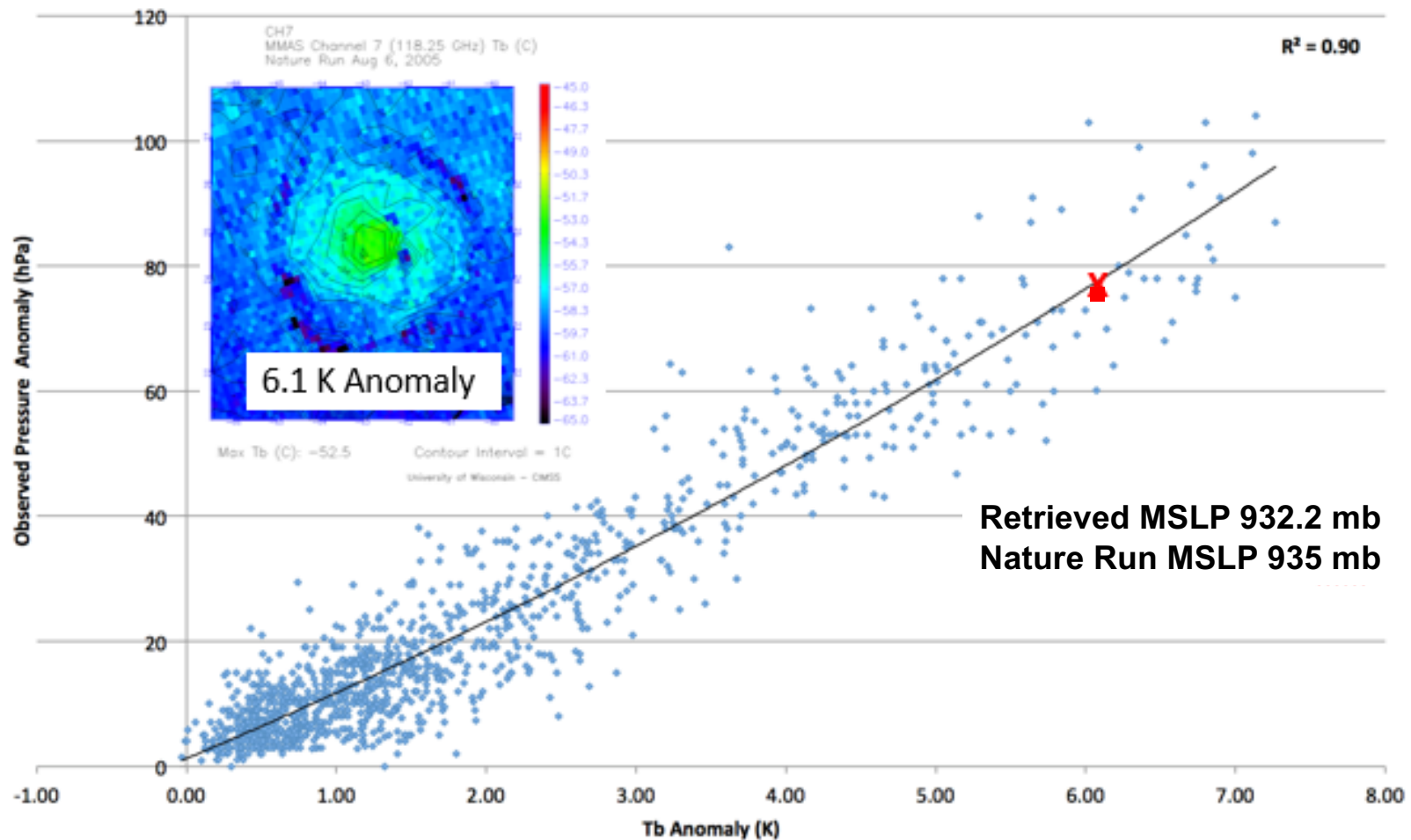
Max Tb (C): -58.9 Contour Interval = 1C
University of Wisconsin - CMSS



Intensity (MSLP) Estimation Strong Storm: 110 kn



TROPICS Channel 7 Estimated Tb Anomaly Compared to Observed TC Pressure
Anomaly Using AMSU Data



Retrieved MSLP 932.2 mb
Nature Run MSLP 935 mb



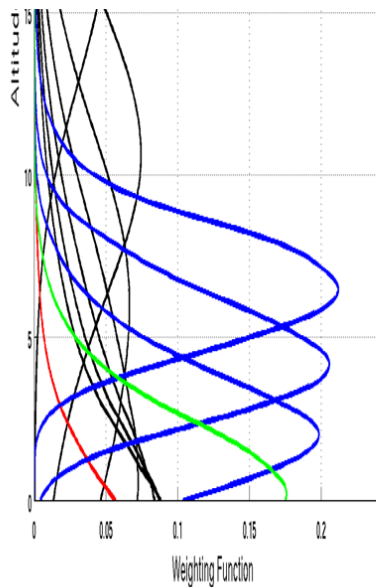
Simulated Warm Core Anomalies

Weak Storm: < Cat 1

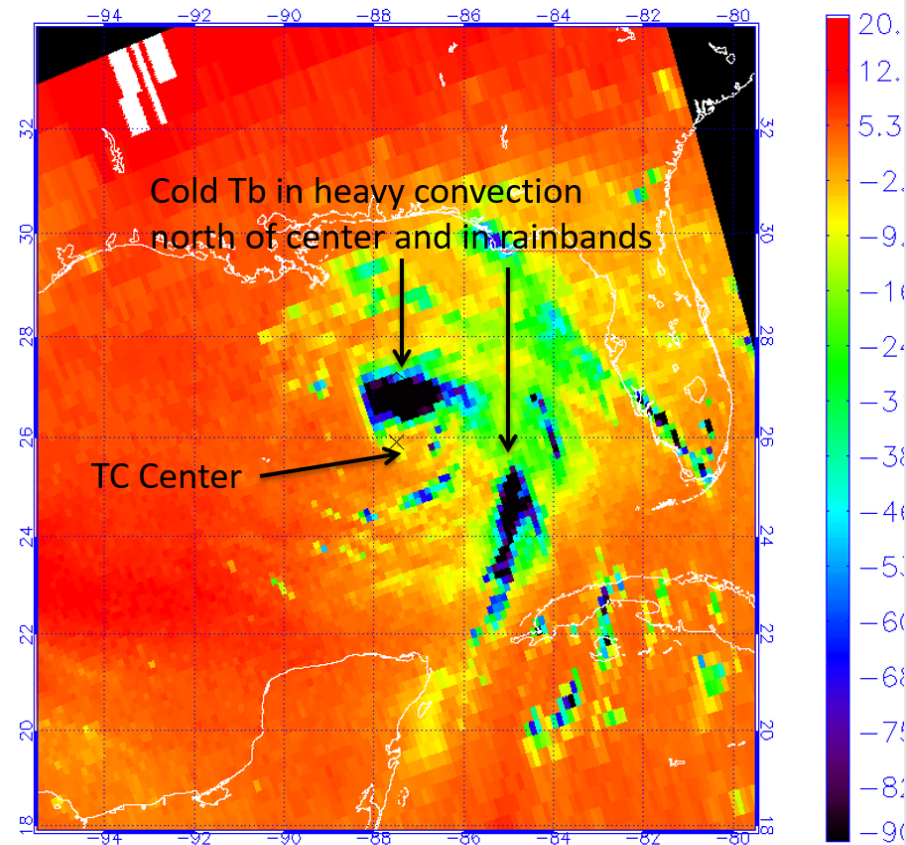


MicroMAS-2 Channel 12

Weak tropical cyclone with
an intensity ~ 40 knots



CH12
MMAS Channel 12 (205 GHz) Tb (C)
Nature Run Sep 9, 2006



Max Tb (C): 17.0

Contour Interval = 1C

University of Wisconsin - CIMSS



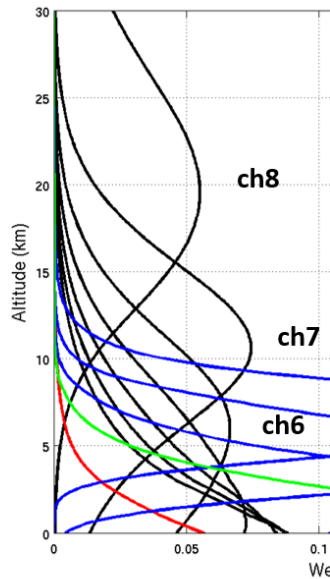
Simulated Warm Core Anomalies

Weak Storm: < Cat 1

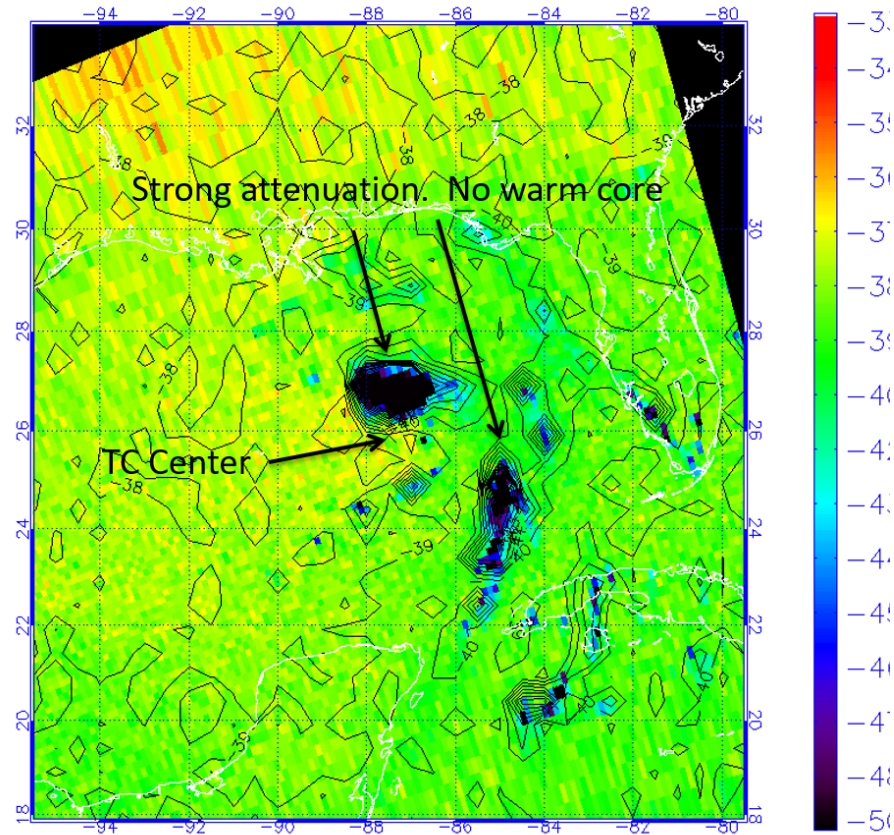


MicroMAS-2 Channel 6

Weak tropical cyclone with
an intensity ~ 40 knots



CH6
MMAS Channel 6 (117.8 GHz) Tb (C)
Nature Run Sep 9, 2006



Max Tb (C): -36.4

Contour Interval = 10

University of Wisconsin - CIMSS

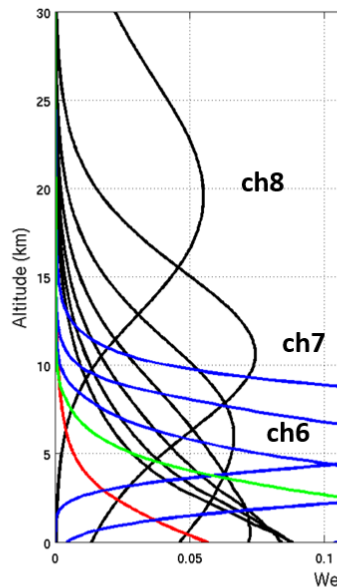


Simulated Warm Core Anomalies Weak Storm: < Cat 1

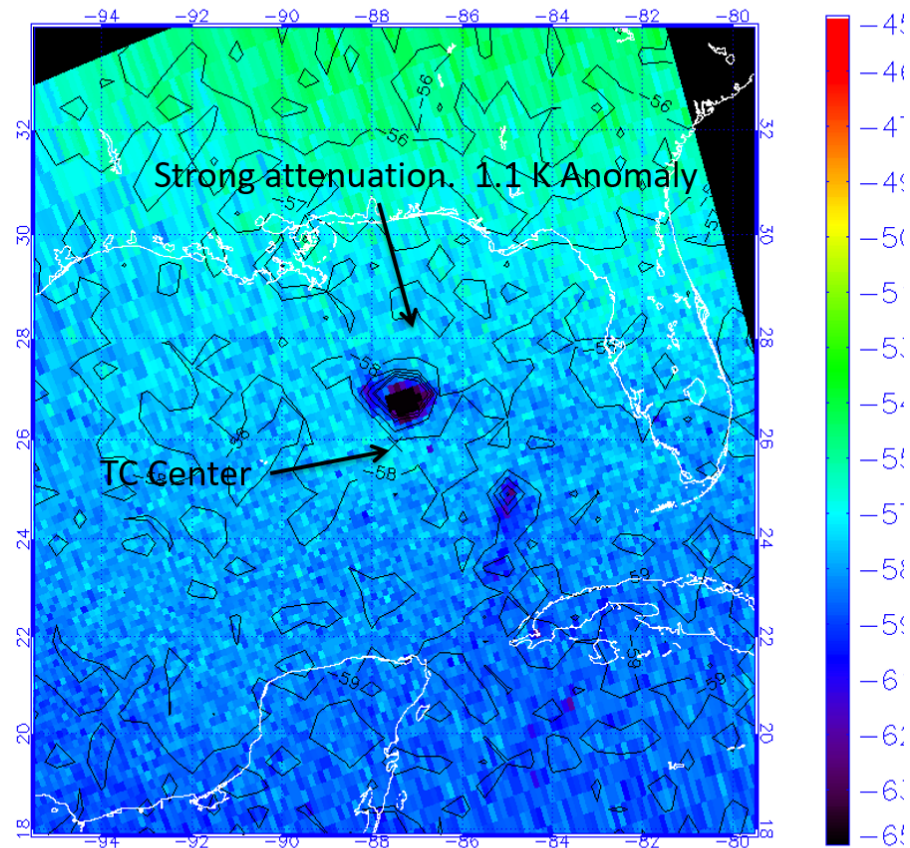


MicroMAS-2 Channel 7

Weak tropical cyclone with
an intensity ~ 40 knots



CH7
MMAS Channel 7 (118.25 GHz) Tb (C)
Nature Run Sep 9, 2006



Max Tb (C): -54.5

Contour Interval = 1C

University of Wisconsin - CIMSS



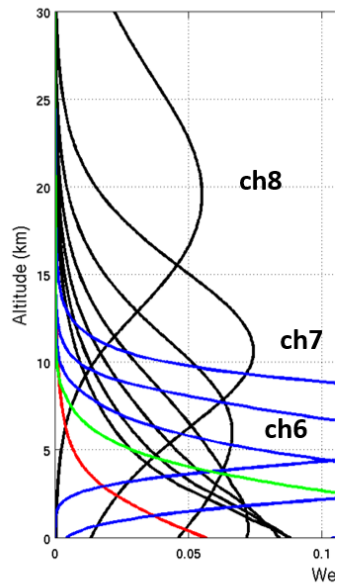
Simulated Warm Core Anomalies

Weak Storm: < Cat 1

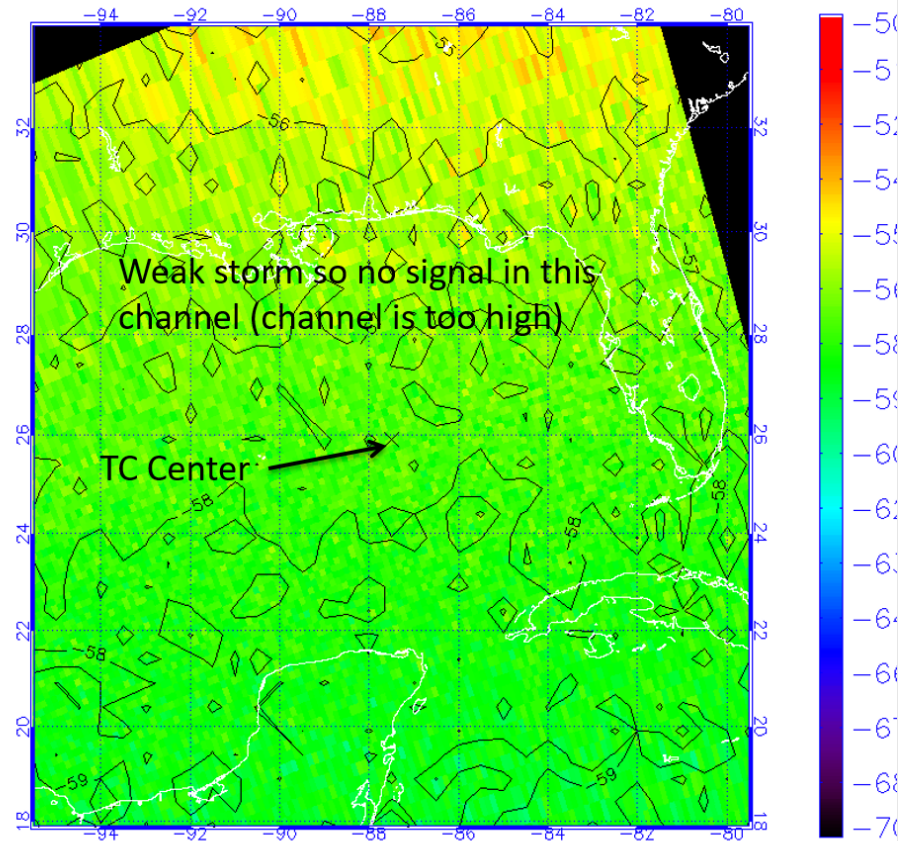


MicroMAS-2 Channel 8

Weak tropical cyclone with
an intensity ~ 40 knots



CH8
MMAS Channel 8 (118.65 GHz) Tb (C)
Nature Run Sep 9, 2006



Max Tb (C): -54.1

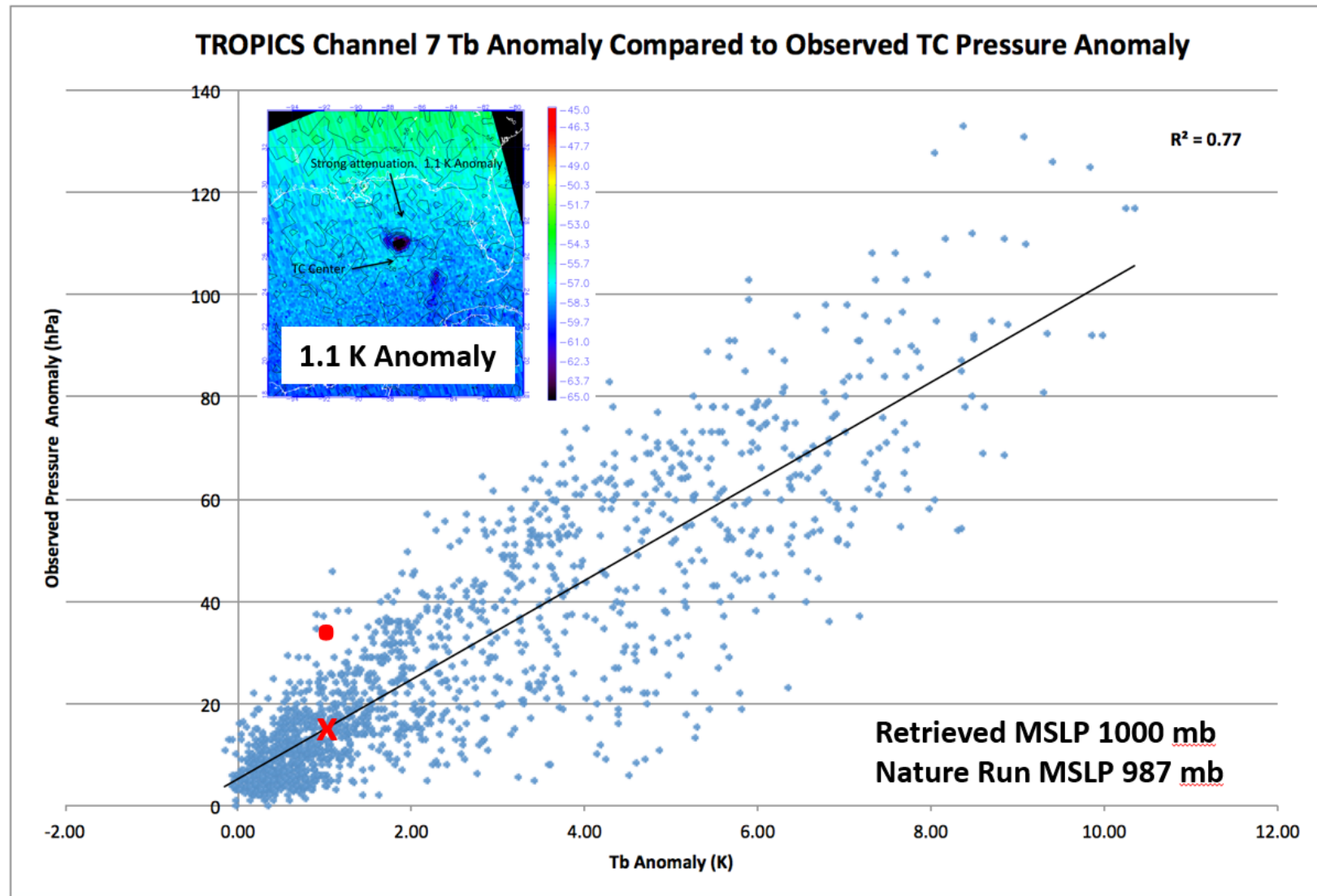
Contour Interval = 1C

University of Wisconsin - CIMSS



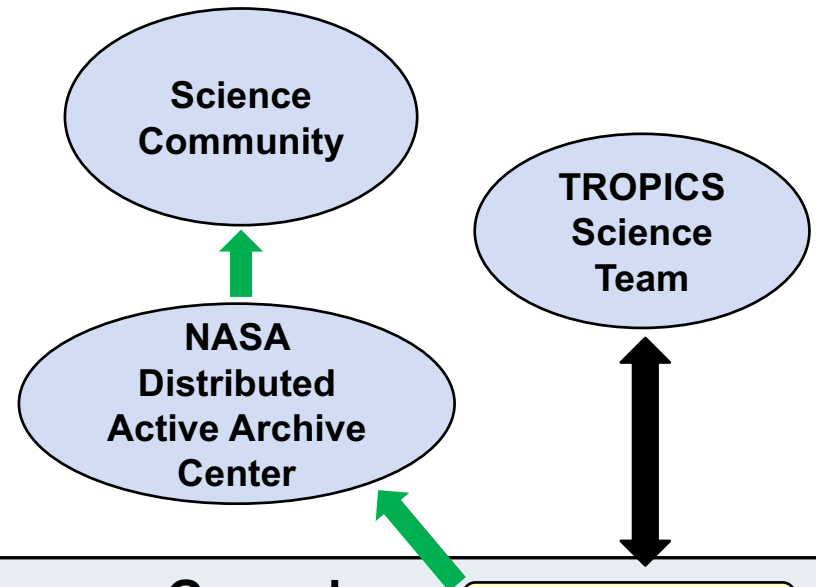
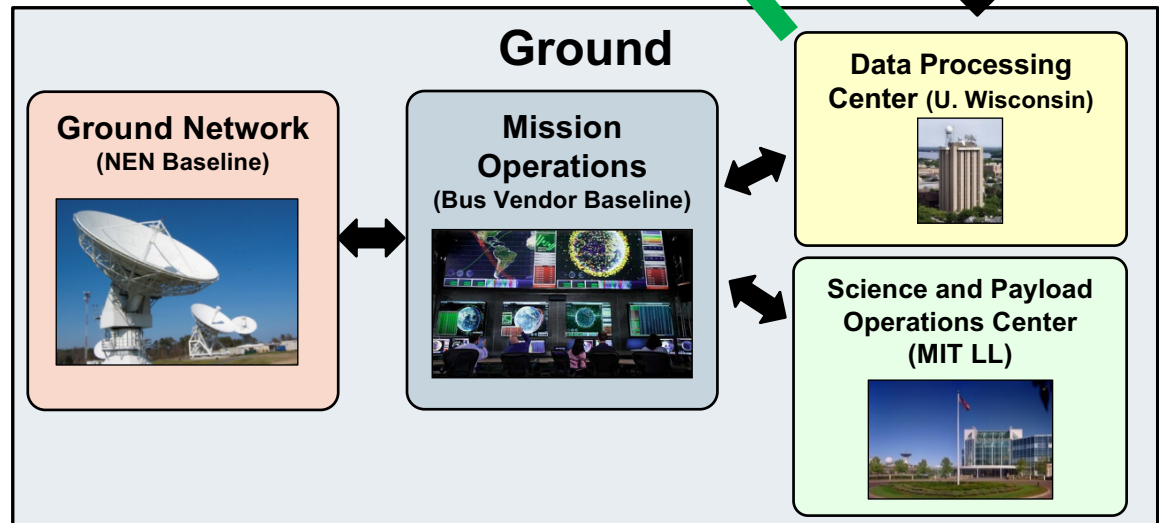
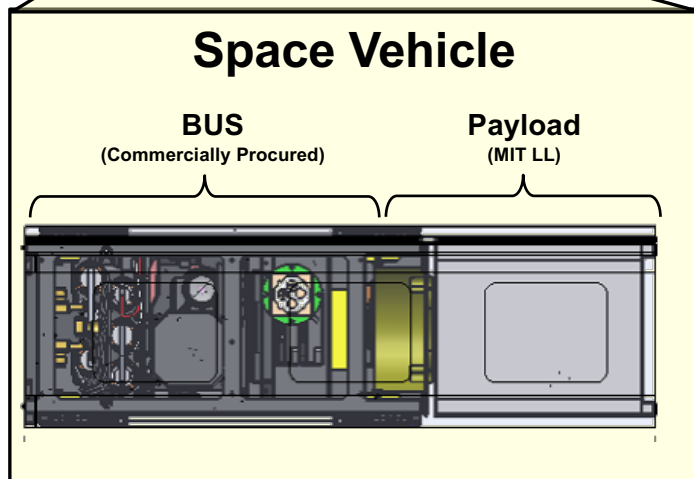
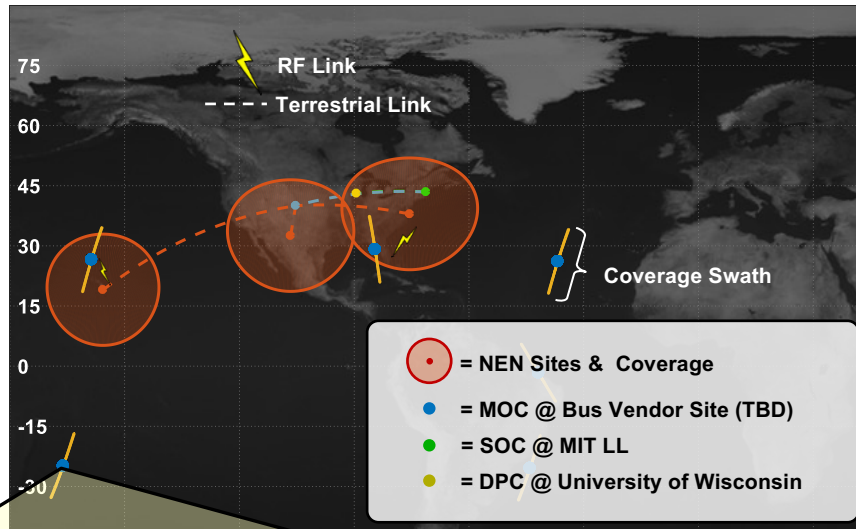
Simulated Warm Core Anomalies

Weak Storm: < Cat 1



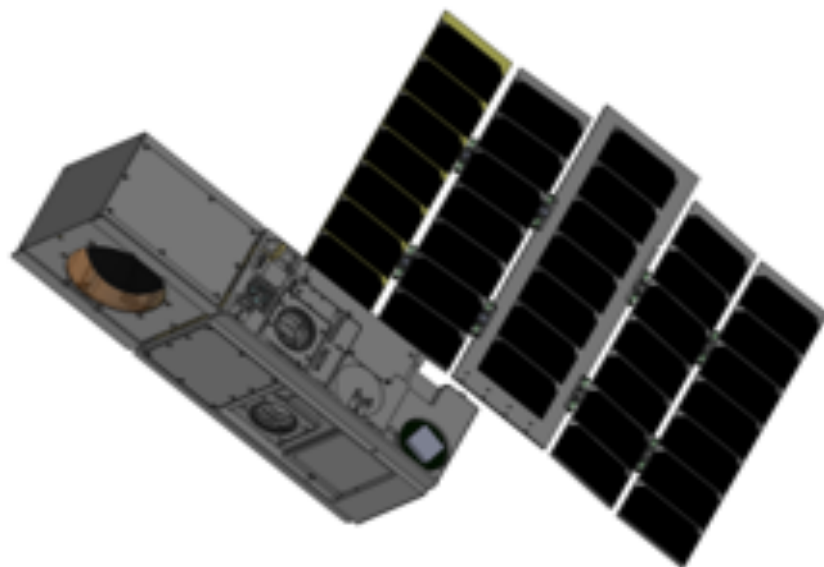


TROPICS Mission Implementation





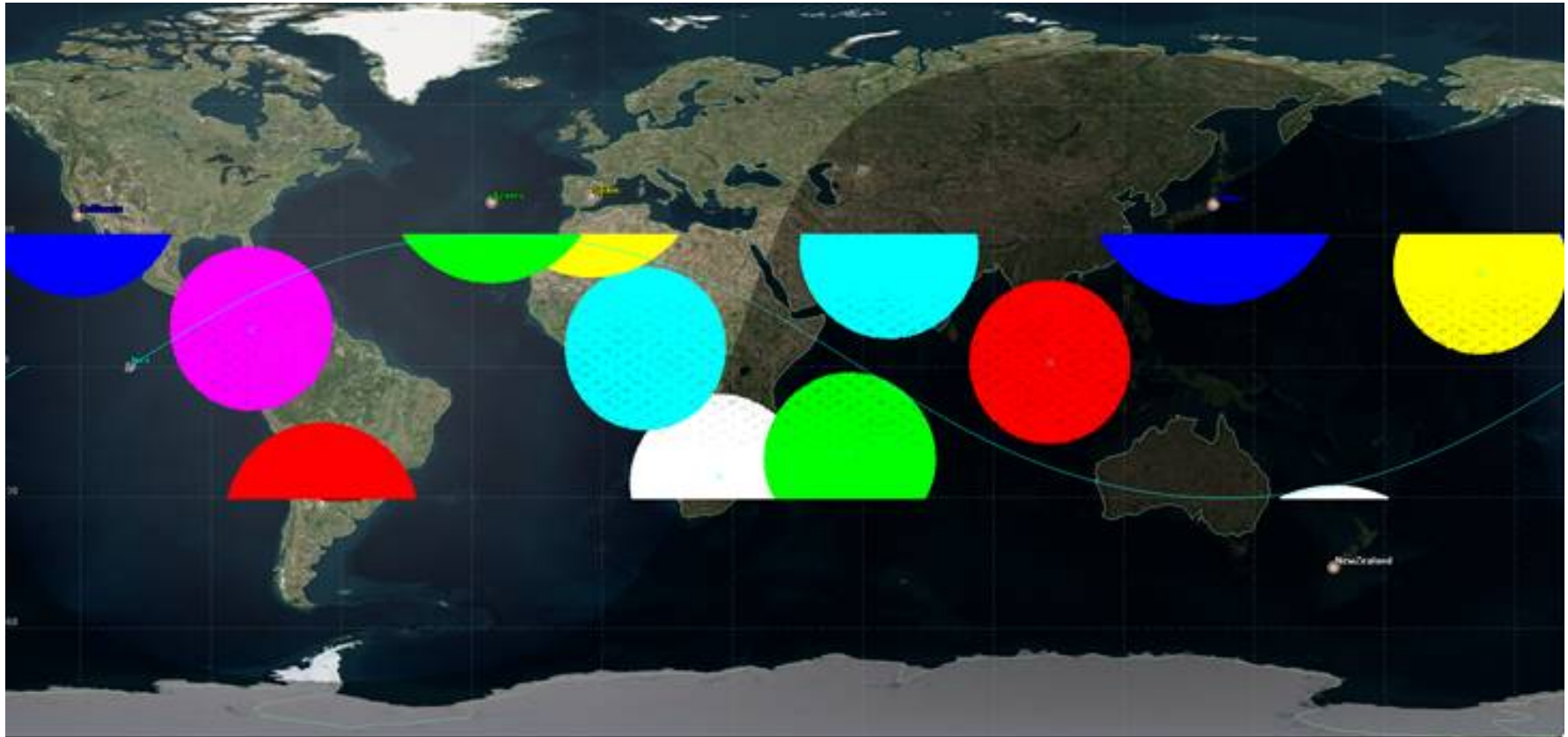
Blue Canyon Technologies Selected to Provide TROPICS Buses



- Based on XB Nanosat bus
- S-band radio
- Articulated solar array



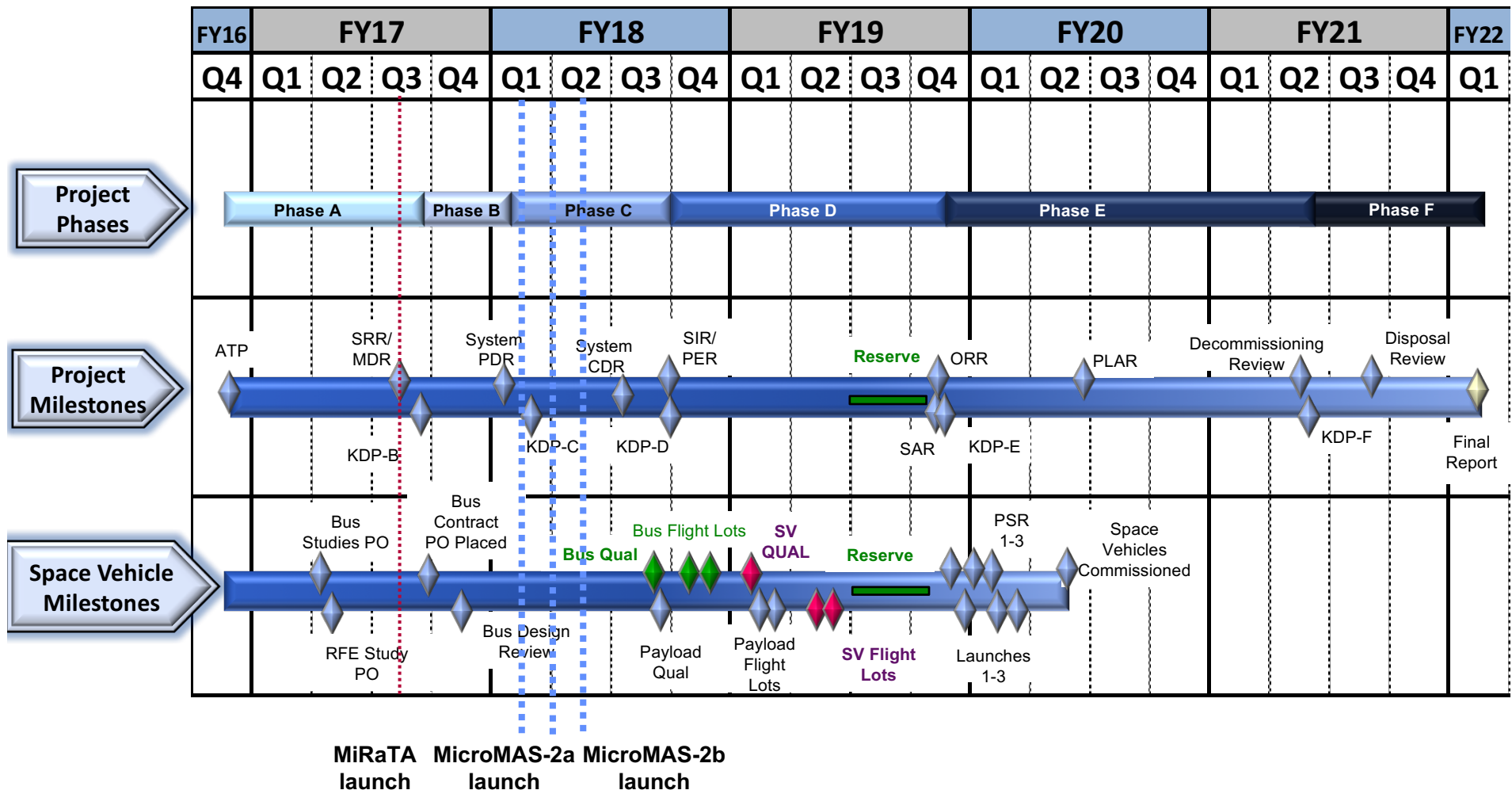
Existing Ground Networks Can Provide Latency <15 min



Currently operational KSAT S-band ground stations in view of the TROPICS constellation



TROPICS Top Level Schedule





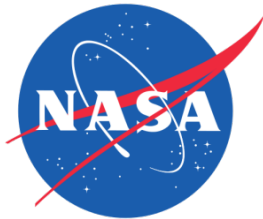
Summary



- **We can now use a constellation of CubeSats to determine thermodynamic relationships in rapidly evolving storms**
 - **99% Tropical Cyclone coverage with 30° inclination orbital planes**
- **TROPICS will provide the first high-revisit microwave observations of precipitation, temperature, and humidity**
 - **Existing commercial ground networks can offer 15-min latency**
- **Measurements will complement GPM, CYGNSS, and GOES-R missions with high refresh, near-all-weather measurements of precipitation and thermodynamic structure**
- **Program ramping up now for 2019/2020 launch readiness**



Backup





TROPICS Team



Regional assimilation; intensity and track forecasting; cal/val



Data processing center; Level 2 algorithm lead; storm intensity products



On-orbit radiometric validation



Receiver front end development



Project Scientist; global modeling and assimilation



CubeSat engineering support



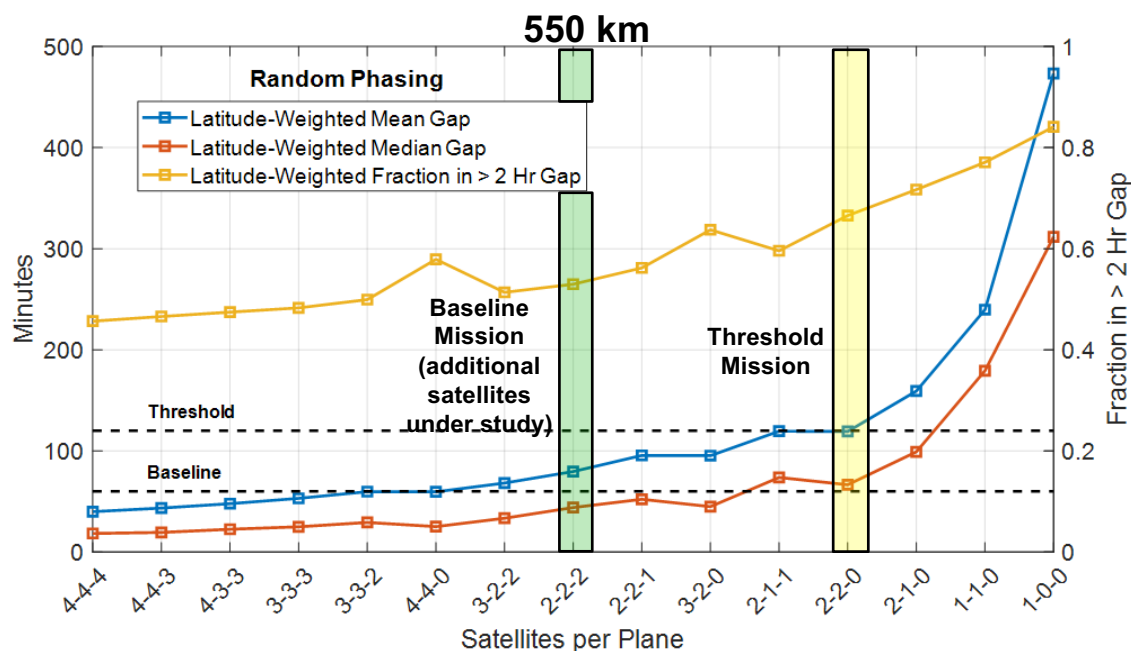
Geolocation optimization and validation



Constellation orbital analysis



TROPICS Revisit



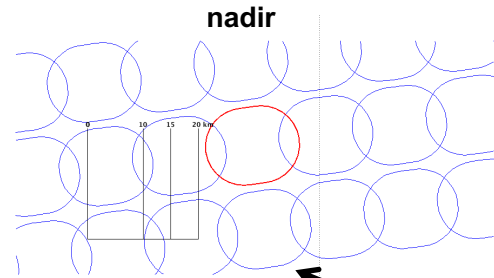
	Average (min)	Median (min)	Frequency of gaps < 2 hr
8 satellites	60	30	55%
6 satellites	75	40	45%
4 satellites	120	70	25%

Current Baseline

Trade study underway to determine the optimal number of satellites (science, reliability, cost)



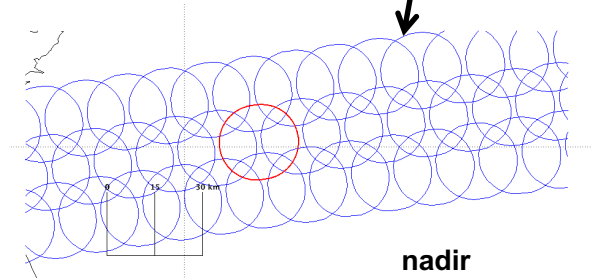
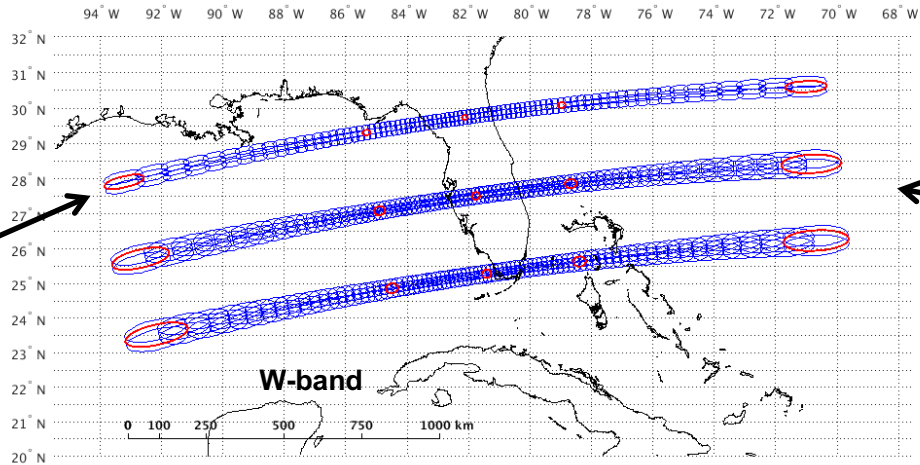
TROPICS Swath & Footprints



30 RPM scan rate
8.333 msec integration time
27 km nadir resolution (T)
17 km nadir resolution (WV)
>2000 km swath ($\pm 56^\circ$)

G-band

Altitude of 500 km

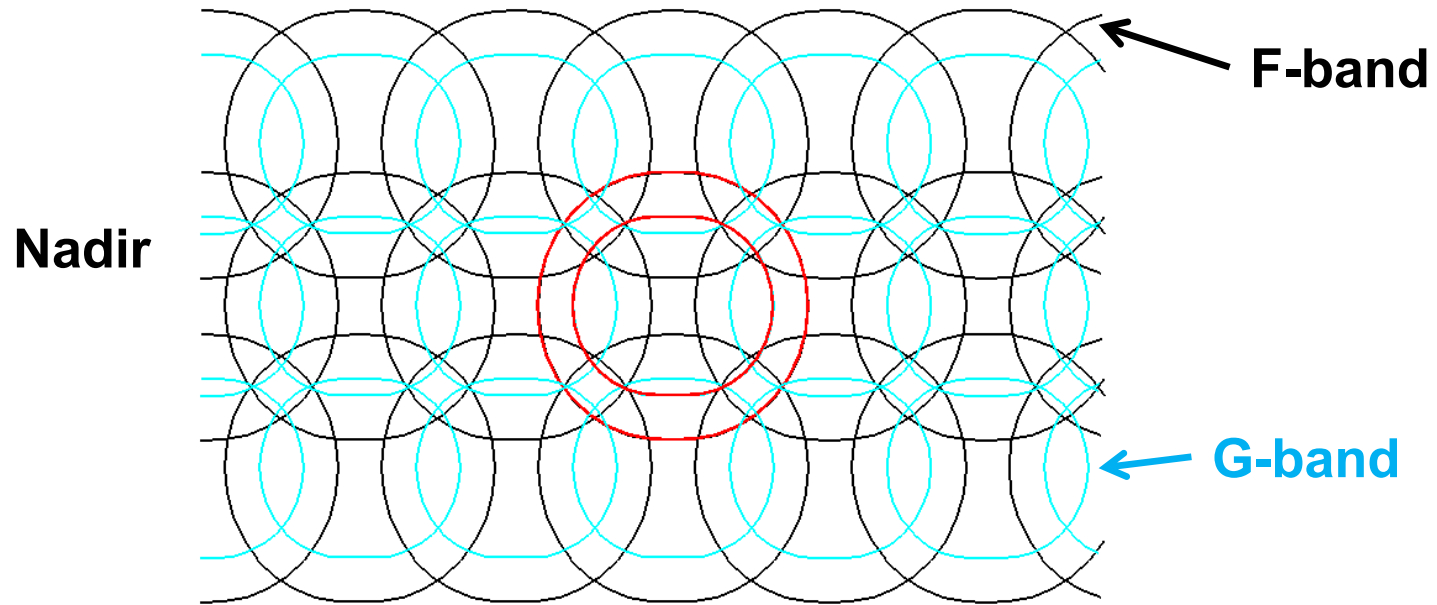


**TROPICS resolution
comparable to ATMS**

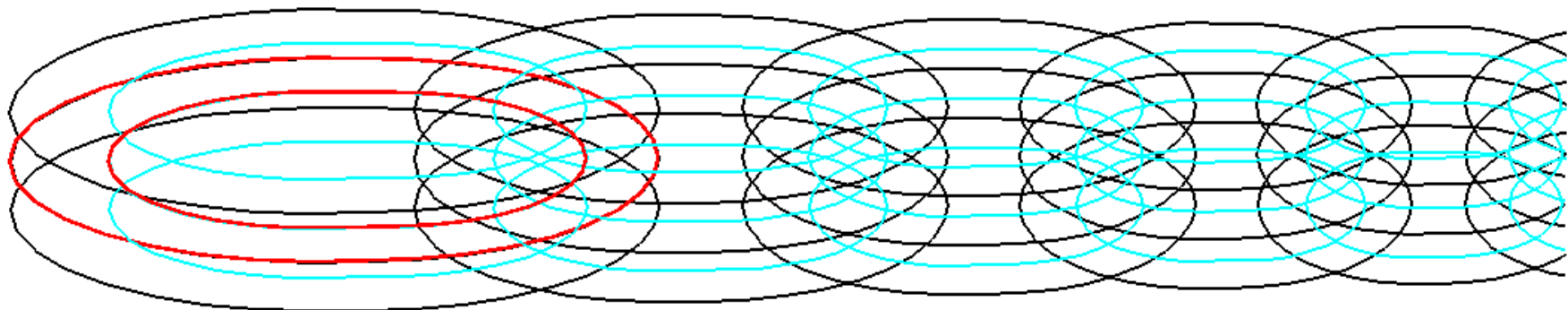
	ATMS Nadir/Avg (km)	TROPICS Nadir/Avg (km)
Temperature	33/44	27/40
Moisture & Precipitation	17/24	17/24
90-GHz Imaging	33/44	35/52
Swath width	2250 ($\pm 50.5^\circ$)	2025 ($\pm 56^\circ$)



TROPICS F-Band & G-Band

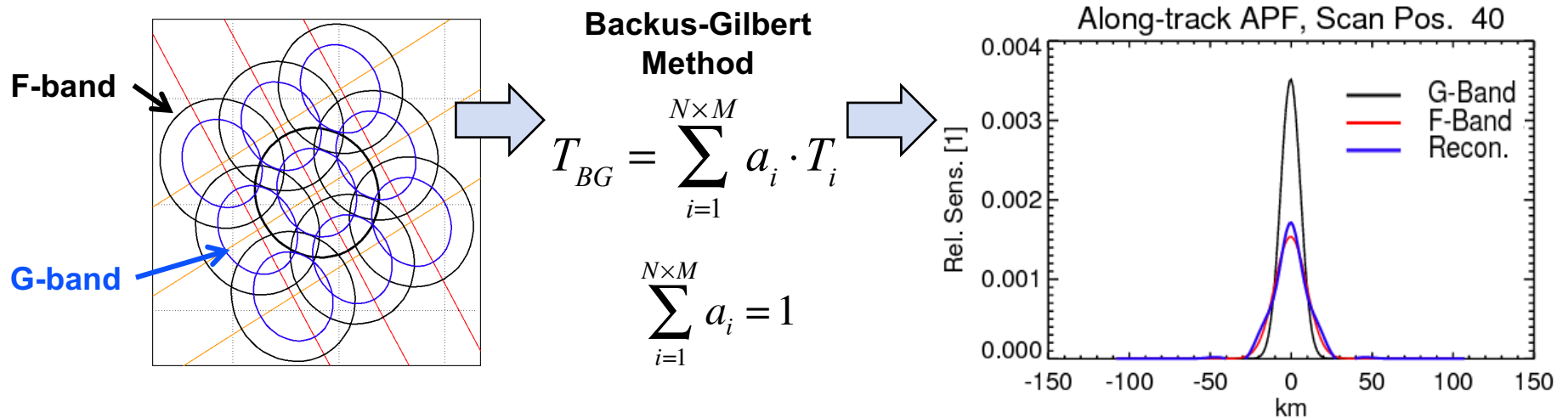


Edge of Scan





Resampling G-band to F-band



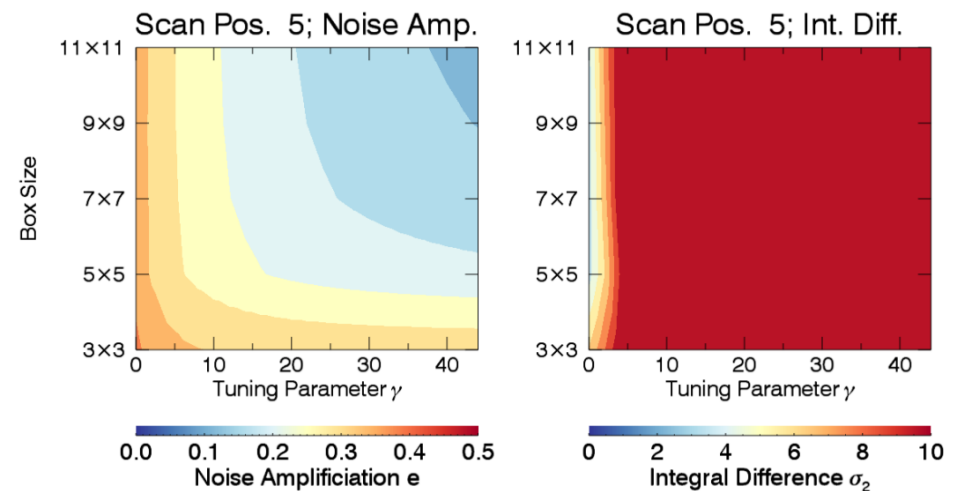
Noise Amplification

$$e = \sqrt{\sum_{i=1}^{N \times M} a_i^2}$$

Results under
perfect conditions
(i.e., preliminary)

Goodness of fit

$$\sigma_2 = 50 \cdot \iint_{X Y} \left\| G_T(x, y) - \sum_{i=1}^{N \cdot M} a_i \cdot G_{EFOV, i}(x, y) \right\| dx dy$$





Small Satellite Launch Segment is Rapidly Maturing



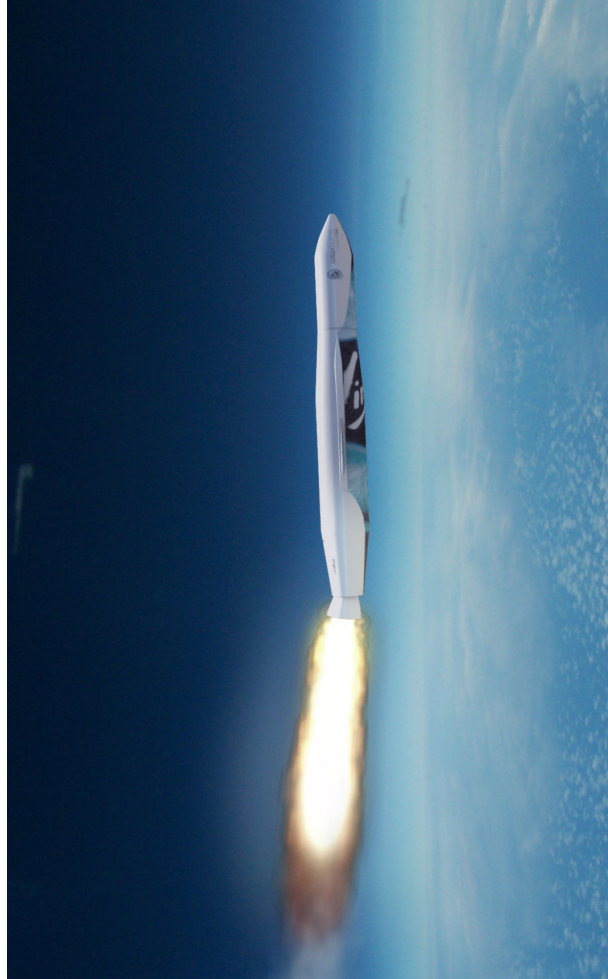
Rocket Lab

>\$1B Company; suborbital flight



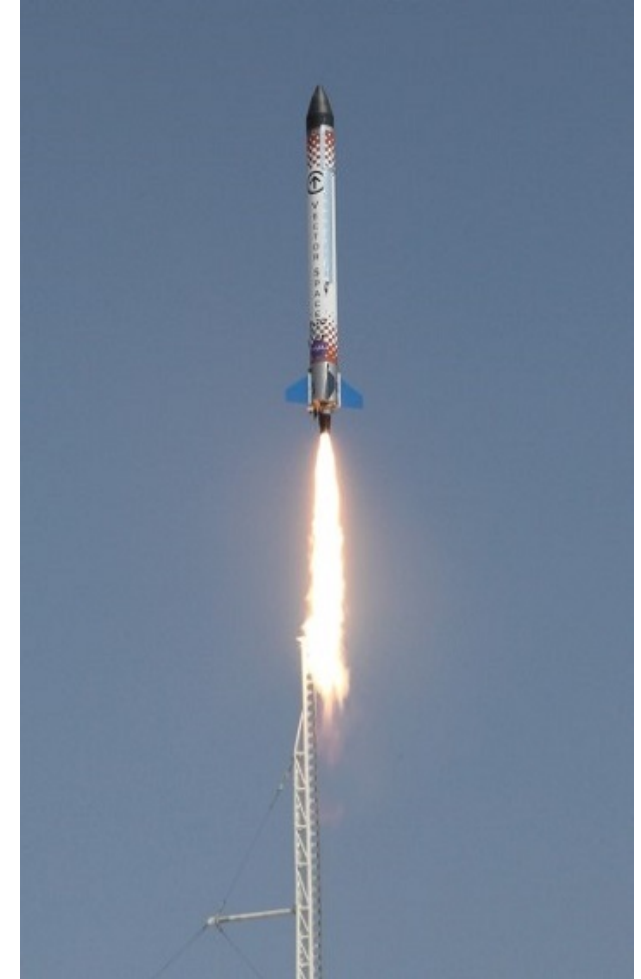
Virgin Orbit

>200 Employees; OneWeb support



Vector Space

Successful suborbital flight





TROPICS Launch RFI Complete





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TROPICS Sources Sought

Solicitation Number: NNK17ZLS002L
Agency: National Aeronautics and Space Administration
Office: Kennedy Space Center
Location: Office of Procurement

[Notice Details](#) [Packages](#) [Interested Vendors List](#)  

 **Original Synopsis**
Aug 08, 2017 8:16 am

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Solicitation Number: NNK17ZLS002L **Notice Type:** Sources Sought

Synopsis:
Added: Aug 08, 2017 8:16 am
The National Aeronautics and Space Administration (NASA) Kennedy Space Center (KSC) is hereby soliciting information about potential sources for dedicated or rideshare launch services, or a combination thereof, for the Time-Resolved Observations of Precipitation Structure and Storm Intensity with a Constellation of Smallsats (TROPICS) mission. TROPICS will perform observations of tropical storm activity and will require multiple CubeSats in orbit in order to make frequent observations of storm targets (mean revisit time of 60 minutes; no more than 3-hour coverage gaps). Therefore, 6 to 8 TROPICS CubeSats will be placed in a constellation formation as described in the three scenarios included in the attached document. All of the CubeSats are identical and must be placed into their operational orbit within 60-days (first insertion to final insertion). The launches are anticipated to occur in the calendar year 2020.

ALL FILES

 [TROPICS Sources Sought](#) 
Aug 08, 2017
 [TROPICS Sources Soug...](#)

GENERAL INFORMATION

Notice Type:
Sources Sought

Posted Date:
August 8, 2017

Response Date:
Sep 04, 2017 5:00 pm Eastern

Archiving Policy:
Manual Archive

Archive Date:
-

Original Set Aside:
N/A

Set Aside:
N/A